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The Reflecting Power Of The Alkali Metals.

THE REFLECTING POWER OF THE ALKALI METALS

BY

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY JONAS BERNARD NATHANSON

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I INTRODUCTION

The beginning of the modern scientific investigation of reflection and refraction dates back to the early part of the nineteenth century. Before the time of Fresnel, Cauchy and Neumann, little interest was displayed in the investigation of these phenomena but the establishment by Fresnel of the equations of reflection and refraction based upon the elastic solid ether theory of light, and the extension of these equations to the case of metals by Cauchy, mark the real beginning of the modern experimental and theoretical attack upon this problem.

The phenomenon of polarization had suggested to Fresnel that the medium through which light energy is propagated, must be an elastic solid capable of yielding transverse vibrations, and acting upon this suggestion, he worked out the equations for the amplitudes of the reflected and refracted waves for transparent media. Subsequently, Cauchy extended Fresnel's theory to the case of metals, by assuming a large index of absorption, and by replacing the index of refraction in the case of transparent media, by an imaginary index for the case of metals. These theories for reflection and refraction of light for metals and non-metals have served as the impetus for much experimental investigation up to the present.

The advent of Maxwell's famous electro-magnetic theory of light in the latter half of the nineteenth century, though putting a new meaning on the terms involved in the formulae of Fresnel and Cauchy, did not however change the ultimate value of the results obtained by the use of these formulae. Maxwell's theory showing the wonderful connection between electrical and optical phenonema, demonstrated that there must be a definite relation between the reflecting

power of a metal and its electrical conductivity. Investigation showed, however, that there is a discrepancy between theory and experiment, except for very long wave lengths. It was left to the electron theory to explain this discrepancy, Maxwell's theory not having taken account of the effect of the electrons.

The alkali metals, by virtue of their great chemical activity, and their interesting electrical and optical properties, have offered interesting fields for research. The great difficulty in handling the metal has, however, limited their investigation. Further interest in these metals has been added by the comparatively recent study of the photoelectric effect in alkali metals. It has been found that two distinct photoelectric effects appear, the normal and selective, depending upon the position of the plane of polarization of the incident light. In the normal effect, with the plane of polarization parallel to the plane of incidence, the photoelectric current increases regularly and continuously with decreasing wave length. However, in the selective effect, with the plane of polarization perpendicular to the plane of incidence, the photo-electric effect increases at first much more rapidly with decreasing wave length but soon reaches a maximum and decreases again, so that the selective effect appears like a resonance phenomenon. It has been suggested that this effect might be due to peculiar optical properties of the metals in the region of the selective effect. If such is the case, there ought to be a marked change in the reflecting powers of the alkali metals in the region of the selective effect.

Consequently, for all reasons enumerated, any knowledge of the optical properties of the alkali metals as a function of the

wave length and plane of polarization, is highly desirable, and it is to this end that this investigation was carried out.

II THE GENERAL METHOD

There are two general methods of attack in the determination of the reflecting power of a metal; namely, a direct or dioptic method, and an indirect or katopric method. The direct method is based upon the determination of the light intensity of a beam before and after reflection, the measuring instrument being either some sort of a spectro-photometer, or more preferably some instrument which can register radiant energy by means of a readable deflection.

The indirect or katopric method is based upon a study of the state of polarization of the light before and after reflection at the metallic surface. The calculations are made from the determination of the principal angle of incidence and principal azimuth, the equations employed being derived from theoretical considerations. Since many factors tend to influence the nature of the polarized light on reflection, it is evident that the direct method is the more reliable method. Nevertheless, it must be borne in mind that the index of refraction of a metal can only be determined by this katopric method with any degree of accuracy, since Kundt's prism method does not yield reliably accurate results.

Among the first to use the direct method, employing a deflection instrument, were Mm. F. de la Provostaye and P. Desains[1], who employed a thermopile in the investigation of the reflecting powers of steel, silver, gold and platinum for infra-red light polarized parallel and perpendicular to the plane of incidence.

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1 Ann. de Chim. e. de Phys. 27, 109, 1849; 30, 276, 1850.

S. P. Langley[2] introduced the use of the bolometer in the investigation of radiant energy, his investigations upon reflecting powers of metals being however limited.

H. Rubens[3] made a more extended use of the bolometer in the investigation of the reflecting powers of silver, gold, nickel, copper, and iron. He employed light ranging from = 0.45 μ to about 3 μ.

E. L. Nichols[4] introduced the use of the radio-micrometer in the investigation of silver and quartz, using wave lengths up to 9 μ.

J. Trowbridge[5] extended the use of the radiomicrometer in the study of nickel, gold, copper, iron and silver, using wave lengths up to 15 μ.

Among the best investigations on the reflecting powers of metals is that of E. Hagen and H. Rubens[6] who employed wave lengths ranging from λ = 250 $\mu\mu$ to 14000 $\mu\mu$. The reflecting power was ingeniously determined by a photo-metric comparison of an incandescent platinum filament with its real image formed close to the filament by a cylindrical mirror of the metal under investigation. For ultra-violet and infra-red light, a thermopile was employed in connection with a very sensitive galvanometer. Their results showed a general increase of the reflecting power of a metal with increase

2 Phil. Mag., 27, p.10, 1889

3 Wied. Ann., 37, p.249, 1889

4 Phys. Rev., 4, p.297, 1897

5 Wied. Ann., 65, p.595, 1898

6 Ann. d. Phys., 1, 352, 1900; 8, 1, 1902; 11, 873, 1903.

of wave length.

The instruments so far enumerated are mostly efficient for the visible and infra-red spectrum. Recently, however, the advent of the photo-electric cell in its most sensitive form, i.e., through use of alkali cathodes, has offered to the scientific world the use of an instrument which is very sensitive, for very small wave lengths, i.e., for violet and ultra-violet.

The present investigation makes use of the photo-electric cell in the determination of the reflecting powers of alkali metals, the cell being calibrated in terms of known light intensities. This use of the photo-electric cell for the determination of reflecting powers has been anticipated by E. V. Hulburt[7] whose work appeared during the progress of this investigation. Hulburt studied a large number of metals and non-metals using wave lengths from 180.0 to 380.0 $\mu\mu$. The angle of incidence employed was kept constant being at 18°. It appears that Hulburt assumed a linear relation between the photo-electric current and light intensity, an assumption which in the light of this andother investigations does not seem to be justifiable.

Up to the present investigation no direct method has been employed in the study of the reflecting powers of alkali metals. All our knowledge rests upon the comparatively very few katopric measurements. The first investigation was made by Paul Drude[8] upon the single metal sodium. The reflecting surface was formed by melting the sodium in a vacuum. The reflecting power was calculated from the formula, —

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7 Astro. Phys. Jour., 42, p.205, 1915.

8 Ann. d. Phys., Vol. 64, p.159, 1898

$$R = \frac{n^2(1 + \kappa^2) - 2n + 1}{m^2(1 + \kappa^2) + 2n + 1}$$

where n is the index of refraction and κ is the coefficient of absorption of the metal. These constants were determined from a study of plane polarized light which has become elliptically polarized on reflection. Drude thus obtained a very high value for sodium, i.e., 99.7%.

In 1913, R. W. and R. C. Duncan[9] made a more extended investigation of the optical properties of sodium and potassium as a function of the wave length, employing Drude's method. The metals were in the form of mirrors, i.e., glass backed by metal. The light polarized at an angle of 45° with the plane of incidence was incident at an angle of 45°, upon a leg of a right angle prism whose hypothenuse was in contact with the mirror. This served to eliminate any change of phase or of azimuth of the incident or emergent light when passing through the glass surface.

The constants n and κ were determined by measuring the phase difference and the ratio of the amplitudes of the two components of the reflected light which became elliptically polarized. Their values for Na and K showed that the metals were very highly reflecting, Na being the better of the two.

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9 Phys. Rev., 36, Vol.I, 294, 1913

P A R T I

White, Unpolarized Light

I-Relation Between the Photo-Electric Current and the Light Intensity

The Apparatus:- In the present investigation of the reflecting power of the alkali metals, a photo-electric cell was employed as a photometer. The cell chosen was one of the most sensitive ones made by Dr. Jakob Kunz of this department. The cathode, C, consisted of # rubidium deposited by distillation upon a film of silver. The anode A consisted of a loop of Pt wire. Between the anode and cathode is located a Pt guard ring which is usually earthed to avoid leakage across the glass between the electrodes.

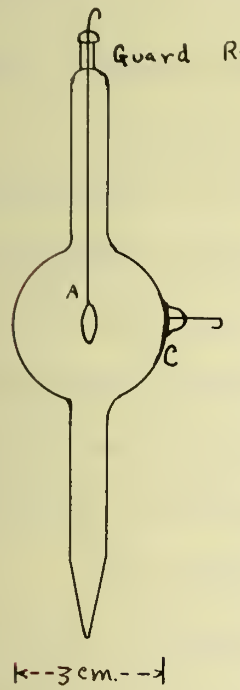

Fig. 1.

Investigations on the relation between the photo-electric current and the light intensity are not in good agreement with each other. While Elster and Geitel[10], and Richtmeyer[11] have shown that the photo-electric current is strictly proportional to the light intensity, on the other hand Lenard[12] and quite recently Ives[13] have shown that the linear relationship does not strictly hold. Ives, in an extended investigation of the subject, wherein he subjected a great variety of cells to different

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10 Ann. d. Phys., 48, 625, 1893.

11 Phys. Rev., 29, 71 and 404, 1909

12 Ann. d. Phys., 8, 149, 1902

13 Astro. Phys. Jour., 39, 428, 1914; 43, 9, 1916.

conditions, showed that the relation is not a linear one, but that the photo-electric current is a complicated function of the voltage, electrode distance and gas pressure in a cell.

Consequently due to the conflicting literature on this subject, it was decided, before using the above cell as a photometer, to first calibrate it in terms of known light intensities by the aid of crossed Nicol prisms. To this end, the arrangement of apparatus shown in Fig. 2 was employed.

A Nernst glower, G, was used as a source of light, both on account of its intensity, and reputation for constancy. The light after passing through several condensing lenses, L, is focused upon the circular aperture of the collimator C, and is rendered parallel after passage through the collimator lens. The light then passes through the Nicols N_1 and N_2, the former having rectangular ends to eliminate rotation of the beam when N_1 is rotated.

The circular beam of parallel rays of light is then incident upon the photo-electric cell which is enclosed in the earthed metallic box, E. This box was air and light tight, and blackened on the inside. It served to eliminate disturbing electrical influence, and to eliminate any possible extraneous light. In this box was placed some phosphorous pentoxide to render the air dry and so to diminish leakage across the glass or across the hard rubber disks through which were conducted the wires leading to the electrodes of the cell. The beam was admitted through a glass window, before which was placed a shutter sliding on a groove, so that by means of a cord and pulleys the shutter could be easily raised or lowered by the observer at his observing station.

ARRANGEMENT OF APPARATUS FOR

WHITE UNPOLARIZED LIGHT.

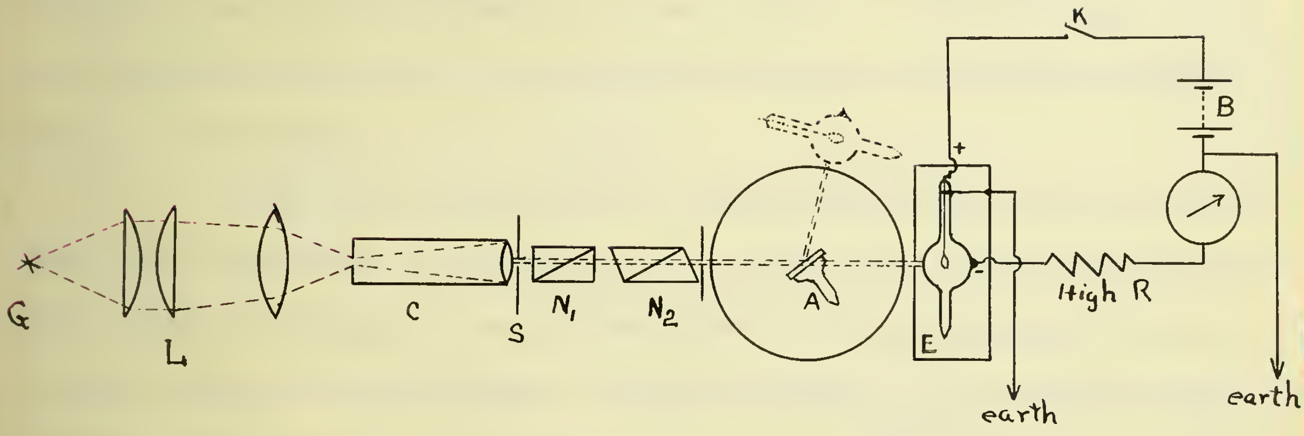


Fig. 2.

The voltage used across the photo-electric cell varied from 111 to 134 volts, this being furnished by a set of constant potential cells. As a detector of the photoelectric current, a very sensitive galvanometer was employed, being loaned to the writer by the astronomy department through the kindness of Professor Stebbins. This galvanometer had a figure of merit of 2×10^{-10} amperes per mm. at a scale distance of 2.5 meters. The terminal of the galvanometer next to the negative pole of the battery was earthed. This was found to be highly essential, serving to eliminate completely troublesome leakage currents in the circuit, and enabling one to take observations with the greatest accuracy in the most humid days of the summer.

It was very essential in this part of the investigation that the intensity of the source of light should be very constant. The light intensity of the Nernst glower varies markedly with a slight change in the current flowing through it. Consequently, the steady current from the storage cells was employed, and by means of an adjustable resistance and a fine reading ammeter, the current was kept very constant.

Method of Observation:- With the axes of the Nicols parallel to each other, the cell was exposed to the light and the galvanometer deflection observed. Then the deflection was observed for some angle between the Nicols. Finally, the Nicols were made parallel again, and the deflection again observed. This last observation served as a check on any fluctuations of the light intensity that might have occurred during the observations. As a matter of fact, the light intensity was absolutely constant only on rare occasions,

there being usually a small and slow variation. However, by continually checking the deflection for zero angle between the Nicols, proper corrections could be applied to the deflection for any angle between the Nicols.

Several readings were always taken for each position of the Nicols. The individual readings usually agreed to within two or three tenths of a mm. for the larger deflections, and to a correspondingly smaller extent for the smaller deflections.

The Results:- In Table I, are given the deflections corresponding to various light intensities, the latter being proportional to the squares of the cosines of the angles between the two Nicols. Each deflection is the average of two to four observations.

Upon examining the plotted results, it is evident that the current-light intensity relation is not a strictly linear one but is in the form of a curve slightly concave towards the illumination axis. The light lines merely serve to indicate the divergence in each case from a straight line. The results for the curve labeled 130 volts were obtained by using a different quadrant of the Nicol prism, N_1. Also the light was somewhat weaker than in the other three cases, hence the smaller deflections. This serves to show that the concavity of the curves can not be due to lack of symmetry of the Nicol prism. This concavity increases with the deflection. In the succeeding determinations of reflecting powers, proper corrections were always made in accordance with these curves.

II Preparation of the Alkali Mirrors

The alkali mirrors were made either by distillation or pouring of the metal upon a square piece of plane glass about 2.5cm. on edge and about 1.74 mm. thick. The cell, C, was made by joining

TABLE I

Galvanometer Deflections Corresponding to Different Light Intensities

		Voltage across cell 111 volts	volts 124.5	volts 125	(Weaker Light) volts 130	volts 134
Angle bet. Nicols θ	$\cos^2\theta$	mm. Deflection	mm. Deflection	mm. Deflection	mm. Deflection	mm. Deflection
0°	1.0000	33.25	53.55	63.43	47.93	80.05
5°	0.9924	32.97	53.40	62.90	47.95	79.50
7.5°	0.9830	———	———	———	———	78.50
10°	0.9698	32.30	52.13	61.50	46.05	78.00
12.5°	0.9532	31.75	51.50	60.50	———	76.30
15°	0.9330	30.72	50.02	59.30	44.53	74.75
17.5°	0.9096	30.18	49.20	57.80	———	73.25
20°	0.8830	29.35	47.52	56.15	42.65	71.20
22.5°	0.8536	28.65	46.25	54.57	———	———
25°	0.8214	27.45	44.85	52.60	———	66.60
30.0°	0.7500	25.30	41.05	47.95	36.20	61.10
35°	0.6710	22.65	37.10	43.25	32.87	55.25
40°	0.5868	19.90	32.45	38.08	29.05	48.50
45°	0.5000	17.15	27.85	32.60	24.60	41.60
50°	0.4132	14.33	23.17	27.30	21.05	34.65
55°	0.3290	11.68	18.70	21.75	15.80	27.80
60°	0.2500	8.80	14.22	16.62	12.27	21.50
65°	0.1786	6.25	10.07	11.85	8.45	15.48
70°	0.1170	4.11	6.66	7.59	5.13	10.00
75°	0.0670	2.60	4.02	4.36	2.78	5.81
80°	0.0302	1.00	1.62	1.83	1.06	2.60
85°	0.0076	0.20	0.50	0.35	0.37	0.74
90°	0.0000	0.00	0.00	0.00	0.00	0.00

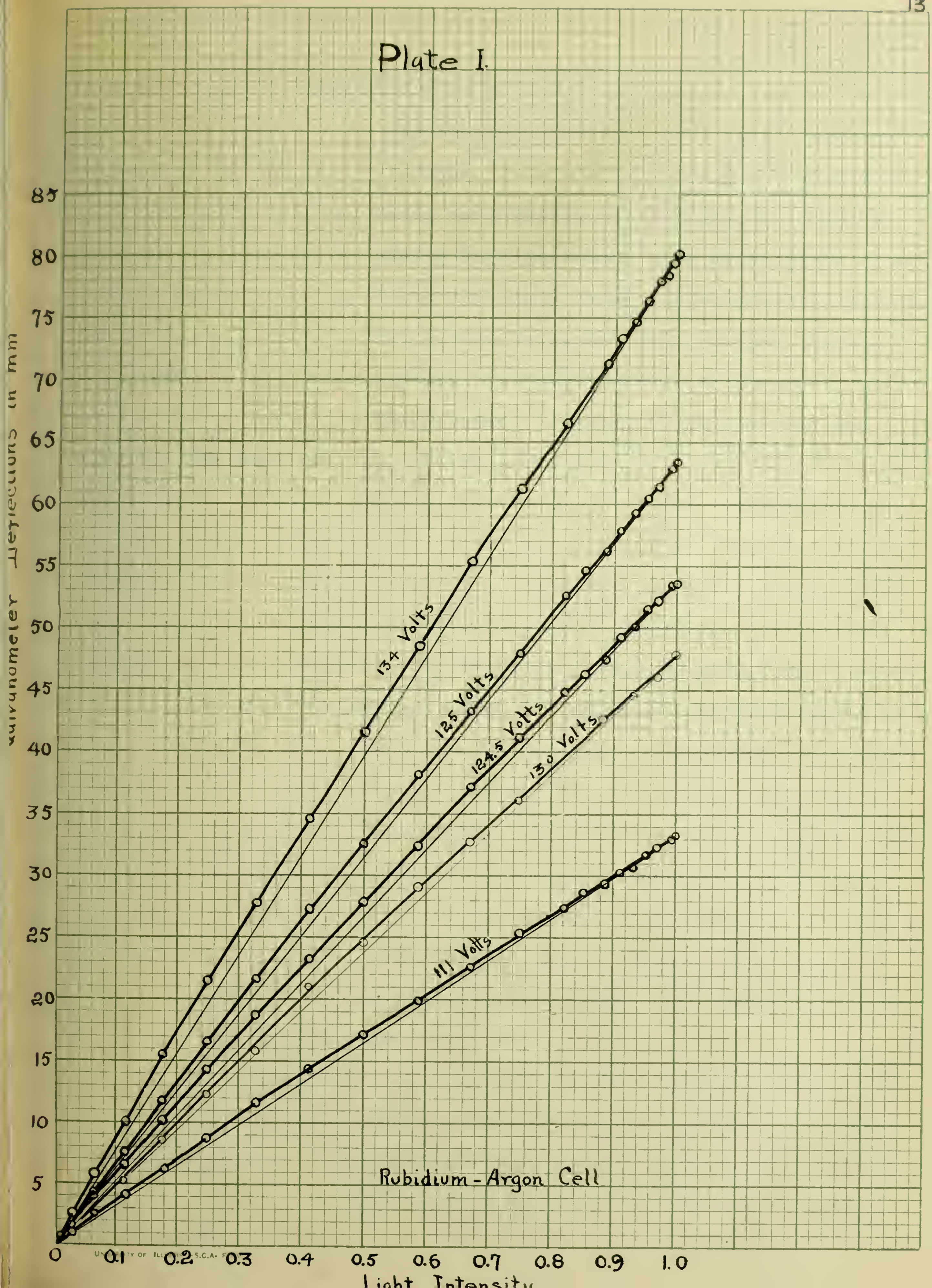


Plate I.
134 Volts
125 Volts
124.5 Volts
130 Volts
111 Volts
Rubidium - Argon Cell
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
Light Intensity

a small piece of glass tubing to a much wider piece. The latter was then cut off leaving a bell shaped opening. The edge of this bell was ground plane with emery and finally with rouge, the edge becoming very polished. The glass plate after being throughly cleaned with alcohol, potash and nitric acid, was then clamped tightly against the polished edge of the bell, and "Rock Cement" applied thickly around the edge A. The bell was then placed in an electric oven, and baked at about 140°C. Usually three applications of cement were applied to the cell. The baking was continued until the cement turned to a brownish color. This cement served very excellently in making the cell air tight, and enabling one to subject the cell to much heat during the distillation of the metal without endangering the vacuum.

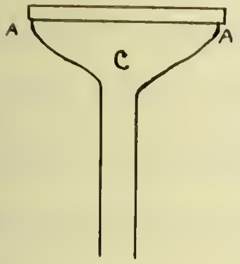


Fig. 3.

The cell was then attached to the glass apparatus shown in Fig. 4. In the case of Na and K, the metal was introduced into A through D which was then sealed off, and the tube evacuated. The metal was then melted down with an electric coil. Great care is necessary in this process, as the glass is apt to crack very easily when the molten metal bursts out of its oxide skin.

A portion of the metal was poured into B, and from there distilled to H. A small molten globule was then guided to the concavity F. In this process the tube was removed

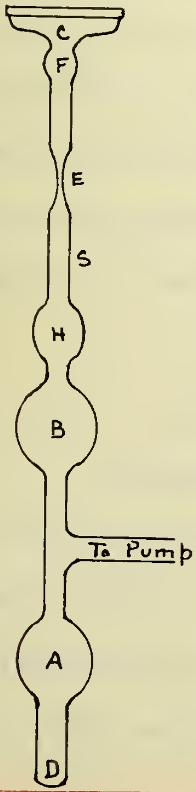


Fig. 4

from the pump, and the globule guided to F by means of successive jars of the hand. The metal was then distilled against the glass plate which wasplaced in contact with a flat piece of ice. The metallic vapor thus deposited itself upon the plate in the form of a mirror, the layer of metal being made thick enough so as to be entirely opaque to light. The mirror was then sealed off and removed at E.

In the case of one of the K mirrors (mirror No.2), a large amount of the metal was collected in H by distillation, and the whole molten mass forced into the cell against the glass plate, making a mirror out of a solid cake of the metal.

Rubidium cannot be obtained on the market in metallic form, and so had to be obtained by reducing RbCl with Ca, the materials being placed in an iron boat enclosed in a hard glass tube attached to D of Fig. 4. The metallic vapor was condensed in A before it was redistilled and deposited upon the glass plate.

Success in making the mirrors was not always attainable, there being many opportunities for failure in the long process. Many of the mirrors after being formed we found to have thin oxide films on their surfaces, and so were discarded. Only those mirrors were picked for investigation which appeared perfect as viewed by the eye.

III
Arrangement of Apparatus for the Determination of the Reflecting Power

In the determination of reflecting powers the arrangement of apparatus shown in Fig. 2 was employed, the Nicol prisms being, however, removed so that the light incident on the mirrors was unpolarized. The metallic box containing the photo-electric cell was

mounted upon the telescope arm of the spectrometer to facilitate the movement of the cell for any angle of incidence desired. The box containing the cell was also placed in a vertical position, so that the lateral space occupied would be as small as possible and so that small angles of incidence could be employed. The wires leading to the cell were loosely supported so as not to interfere with the motion of the cell around the spectrometer.

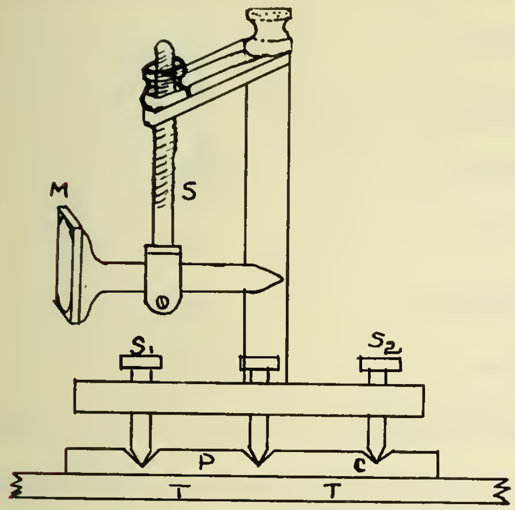


Fig. 5.

The mirror, M, Fig. 5, was mounted on a small tripod, whose legs fitted into cups C on a brass plate P which could be permanently clamped to the top of the spectrometer table T. The center of the reflecting face of the mirror was adjusted to lie along the axis of the spectrometer. After proper adjustment the plate P was clamped to the table T. By this means, the mirror could be removed from the spectrometer table and quickly replaced in its original position. The screw S facilitated the adjustment of the mirror for proper height, while S_1 S_2 served as leveling screws.

Method of Observation for Reflection

With the mirror removed from the spectrometer table, and the beam of light entering the photo-electric cell directly, the steady deflection of the galvanometer was noted, several readings being taken. The tripod supporting the mirror was then placed in the cups on the spectrometer table, and the telescope arm holding the cell was swung around until the reflected light again entered the

cell. The optical path of the beam direct or reflected was thus exactly the same. The deflections being observed, the mirror was removed, the cell swung back to its original position, and readings with the beam direct again taken. This procedure was necessary as a check upon the constancy of the light source. The light intensity usually varied slowly, so that the mean of the deflections (taken before and after observations made on the reflected light), was used as corresponding to the intensity of the unreflected beam during observation of the reflected light. The angles of incidence were determined as follows. The apparatus was so adjusted that the narrow beam passed right through the axis of the spectrometer. The position of the beam on the shutter of the cell box for position A could be accurately noted. With the cell in position B, the mirror stand with the spectrometer table was rotated until the beam was again incident upon the same spot of the shutter. This ensured that the light would always strike the same spot on the photo-electric cell. The difference of positions of A and B being given accurately by θ, the angle of incidence is then $\frac{180 - \theta}{2}$. This is good to within a small fraction of a degree, and therefore sufficiently accurate for this investigation, since the reflecting powers of the metals were found to vary only very slowly with a change in the angle of incidence.

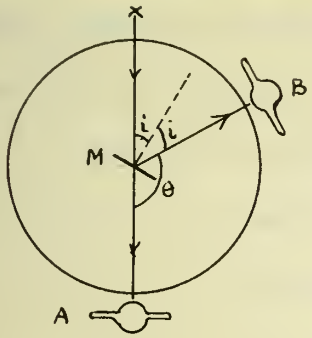


Fig. 6.

IV The Formula

The ratio of the reflected light intensity to the incident light intensity gives only the reflecting power of the whole mirror, i.e., metal plus glass. The greater interest lies in the reflecting

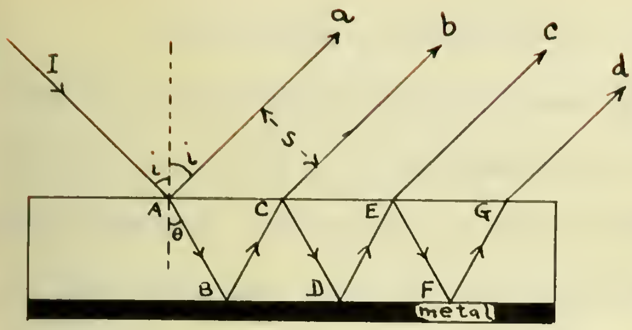


Fig. 7.

power of the metal itself when in contact with the glass. Knowing this, it is possible to form a very close approximation as to what the reflecting powers of the metals would be in contact with a vacuum.

Due to the large number of internal reflections the following mode of reasoning will be used to determine the reflecting power of the metal.

Let I be the light intensity of the incident light.

i = angle of incidence

r = reflecting power of the front face of the glass, i.e., the fraction of the incident light incident on the glass which is reflected back into the air.

r' = reflecting power of the interior glass surface, i.e., for light internally reflected, e.g., as at C, E and G.

t = transmission power of the glass plate for a given thickness, i.e., the fraction of the light which e.g., after penetrating the surface at A, reaches the point B.

R = reflecting power of the alkali metal, i.e., the fraction of the light which incident on the metal glass boundary at B, for example, that is reflected by the metal.

The quantities r, r', t and R are functions of the angle of incidence.

The light intensity at (a) is given by Ir. The light intensity entering into the glass at A is therefore $I(1-r)$. Of this $I(1-r)t$ reaches B, the quantity $I(1-r)tR$ being reflected. At C the incident intensity is $I(1-r)t^2R$ while the intensity reflected by the internal face of the glass is $I(1-r)t^2Rr'$. Hence that which reaches (b) is $I(1-r)(1-r')t^2R$.

By a similar process of reasoning it will be found that the light intensity at (c) is given by $I(1-r)(1-r')r't^4R^2$, and at (d) it is $I(1-r)(1-r')r'^2t^6R^3$, etc., indefinitely.

The photo-electric cell will register the sum of all these components of the total light intensity reflected by the mirror. Let O equal this quantity.

Then $$O = I_r + I(1-r)(1-r')t^2R(1+r't^2R+r'^2t^4R^2+r'^3t^6R^3+\ldots\ldots)$$

Hence, the reflecting power of the whole mirror is given by

$$\frac{O}{I} = r + \frac{(1-r)(1-r')t^2R}{1-r'Rt^2}$$

Hence
$$R = \frac{\frac{O}{I} - r}{t^2(1+\frac{O}{I}r'-r-r')} \quad \ldots\ldots\ldots \qquad (1)$$

This is the formula that was employed in the determination of the reflecting power of the alkali metals. It will be noted that in order to know R, the optical properties of the glass plates used in these mirrors must be determined.

Inspection of Fig.7, shows that the beam after reflection is spread out. If S is the lateral displacement between 2 successive components, then applying Snell's law it follows that

$$S = \frac{t \sin 2i}{\sqrt{n^2 - \sin^2 i}} \quad \ldots\ldots\ldots\ldots \qquad (2)$$

where t = thickness of the glass = 1.74 mm.

i = angle of incidence

n = 1.5155 = index of refraction.

This was determined by means of the Abbe refractometer, using the method of grazing incidence.

Taking i as 60°, the value of S is 1.26 mm. Theoretically an infinite number of internal reflections occur between the metal and the air-glass boundary. Practically, the components of the reflected beam after the fourth one, are negligible. Hence, taking four components as effective, the displacement would be about 5 mm. Adding 3 mm. for the width of the beam, the breadth of the reflected beam does not exceed 8 mm. The aperture to the photoelectric cell was almost 2 cm., hence all effective components of the reflected beam were certainly able to enter the cell.

V Optical Properties of the Glass Plates

In order to determine r, the reflecting power of the front of the glass plate, the back face face was abraided with coarse emery, and then lamp blacked. The results given in Table II embrace investigations carried on two different glass plates, the columns 1, 2 and 3 indicating separate determinations.

The theoretical vlues given in the last column are calculated from Fresnel's equation for reflection for unpolarized light in the case of transparent media.

$$r = \frac{1}{2}\left\{\frac{\sin^2(i-\theta)}{\sin^2(i+\theta)} + \frac{\tan^2(i-\theta)}{\tan^2(i+\theta)}\right\} \cdots\cdots \qquad (3)$$

where θ = angle of refraction. For normal incidence

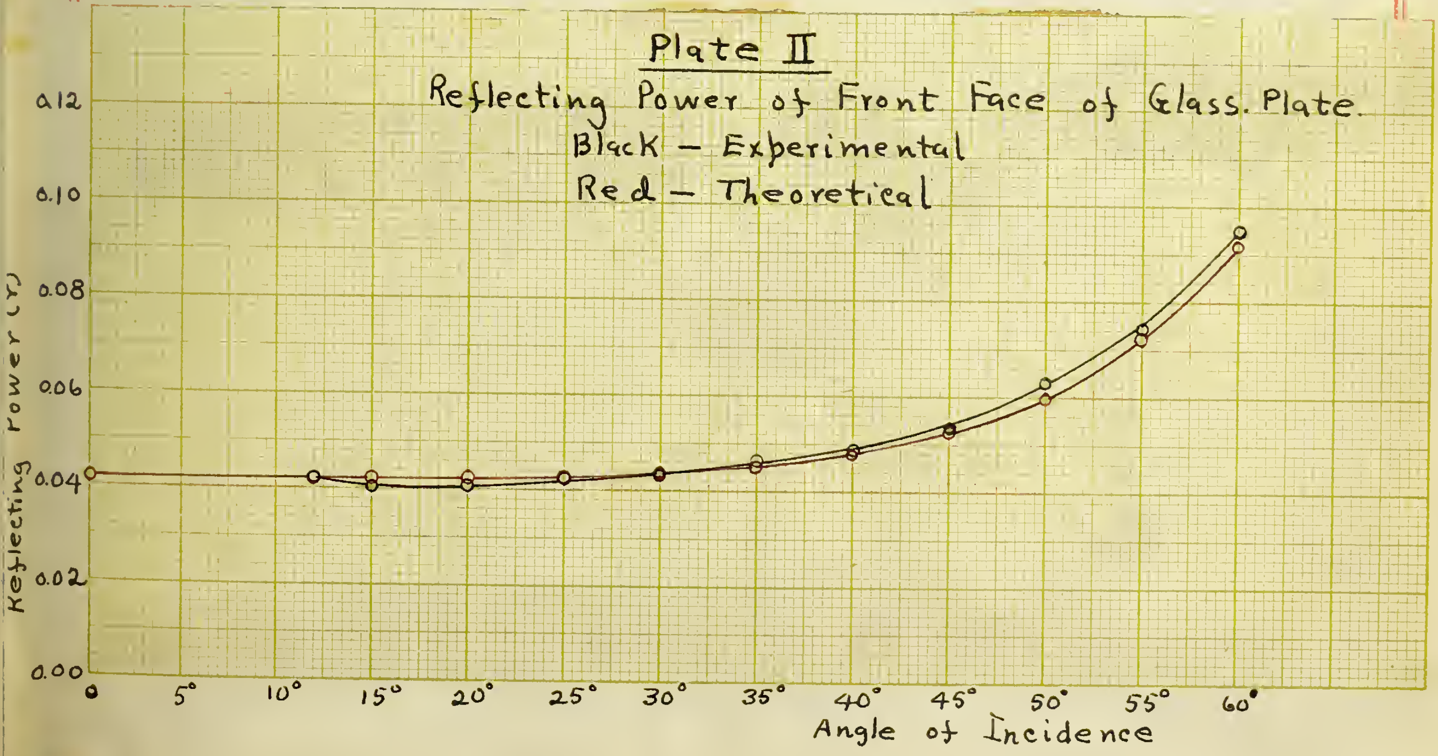
$$r = \frac{(n-1)^2}{(n+1)^2}$$

n being the index of refraction.

TABLE II

Determination of r (unpolarized light)

i	r (Expt) 1	2	3	Mean	r(theor)
0	———	———	———	———	0.0420
12°	0.0440	0.0405	———	0.0423	0.0421
15°	0.0415	0.0390	———	0.0403	0.0421
20°	0.0430	0.0405	0.0390	0.0406	0.0422
25°	0.0433	0.0435	0.0400	0.0423	0.0426
30°	0.0450	0.0420	0.0430	0.0433	0.0435
35°	0.0475	0.0465	0.0450	0.0463	0.0452
40°	0.0525	0.0455	———	0.0490	0.0478
45°	0.0570	0.0530	0.0510	0.0537	0.0524
50°	0.0635	0.0625	———	0.0630	0.0599
55°	0.0725	0.0760	———	0.0743	0.0722
60°	0.0950	———	———	0.0950	0.0918



The experimental and theoretical values are plotted on Plate II. The experimental values which at first are smaller than the theoretical values, are however larger than the latter for larger angles of incidence. This may be due to a possible slight specular reflection of the abraided rear surface which becomes more effective for the larger angles of incidence. In general, the agreement is quite satisfactory, and demonstrates the adaptability of the photo-electric cell as a photometer.

<u>Determination of t and r'</u>

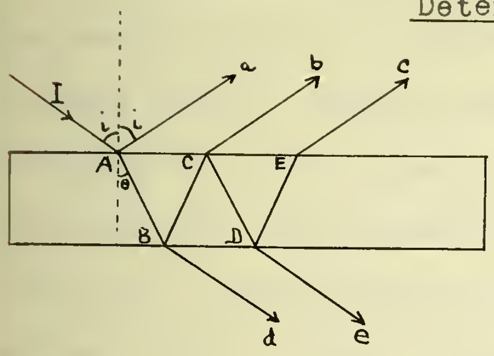


Fig. 8

The determination of the transmission power and reflecting power of internal surface of the glass was affected through a study of the light reflected and transmitted by the glass plate.

Following the method of reasoning employed previously, and adding up the components a, b, c, etc., of the reflected light, we have

$$R' = r + (1-r)(1-r')r't^2 + (1-r)(1-r')r'^3t^4 + \ldots\ldots + \ldots.$$

where R' is the reflecting power of the glass plate (both surfaces).

Or $$R' = r + (1-r)(1-r')r't^2(1 + r'^2t^2 + r'^4t^4 + r'^6t^6 + \ldots\ldots)$$

Hence $$R' = r + \frac{(1-r)(1-r')r't^2}{1 - r'^2t^2} \qquad (4)$$

Considering the light transmitted by the plate, and summing up the components, d, e, etc., we have for the total transmission power, T, of the glass

$$T = (1-r)(1-r')t(1 + r'^2t^2 + r'^4t^4 + \ldots\ldots)$$

Hence $$T = \frac{(1-r)(1-r')t}{1 - r't^2} \qquad (5)$$

combining equations (4) and (5) by division,

$$\frac{R'-r}{T} = r't \tag{6}$$

Solving for t and substituting in equation (5), and then solving for r',

$$r' = \frac{(R'-r)(1-r)}{T^2 + (R'-r)(1-R')} \tag{7}$$

and

$$t = \frac{T^2 + (R'-r)(1-R')}{T(1-r)} \tag{8}$$

The values for r' and t thus are known in known terms. Experimentally, R' is obtained by determining the intensity of the reflected light. Keeping conditions the same T is obtained by merely swinging the cell around on the spectrometer to catch the transmitted light. The summary of various determinations are given in Table III. Mention must be made of the method at arriving at the values for t. Since t appears as the square in the denominator of the expression for the reflecting power of the metal, hence it must be determined with great accuracy. For this purpose the data for angles of incidence less than 45° was taken, since particles of dust or slight irregularities in the glass surface have a more decided effect on the quantity of reflected and transmitted light for large angles of incidence than for small ones. If t is the transmission power for a thickness d of the glass in mm. and if τ is the transmission power per mm. of the glass, then $t = \tau^d$. Knowing t and d, τ was calculated for various angles of incidence, and a mean value obtained. This was found to be 0.9959. From this mean value of τ, the values of t for the various angles of incidence was found. The thickness d of the glass for various angles of incidence was calculated by the formula

$$d = \frac{ns}{\sqrt{n^2 - \sin^2 i}} \tag{9}$$

where n = index of refraction = 1.5155

s = thickness of glass plate for normal incidence = 1.74 mm.

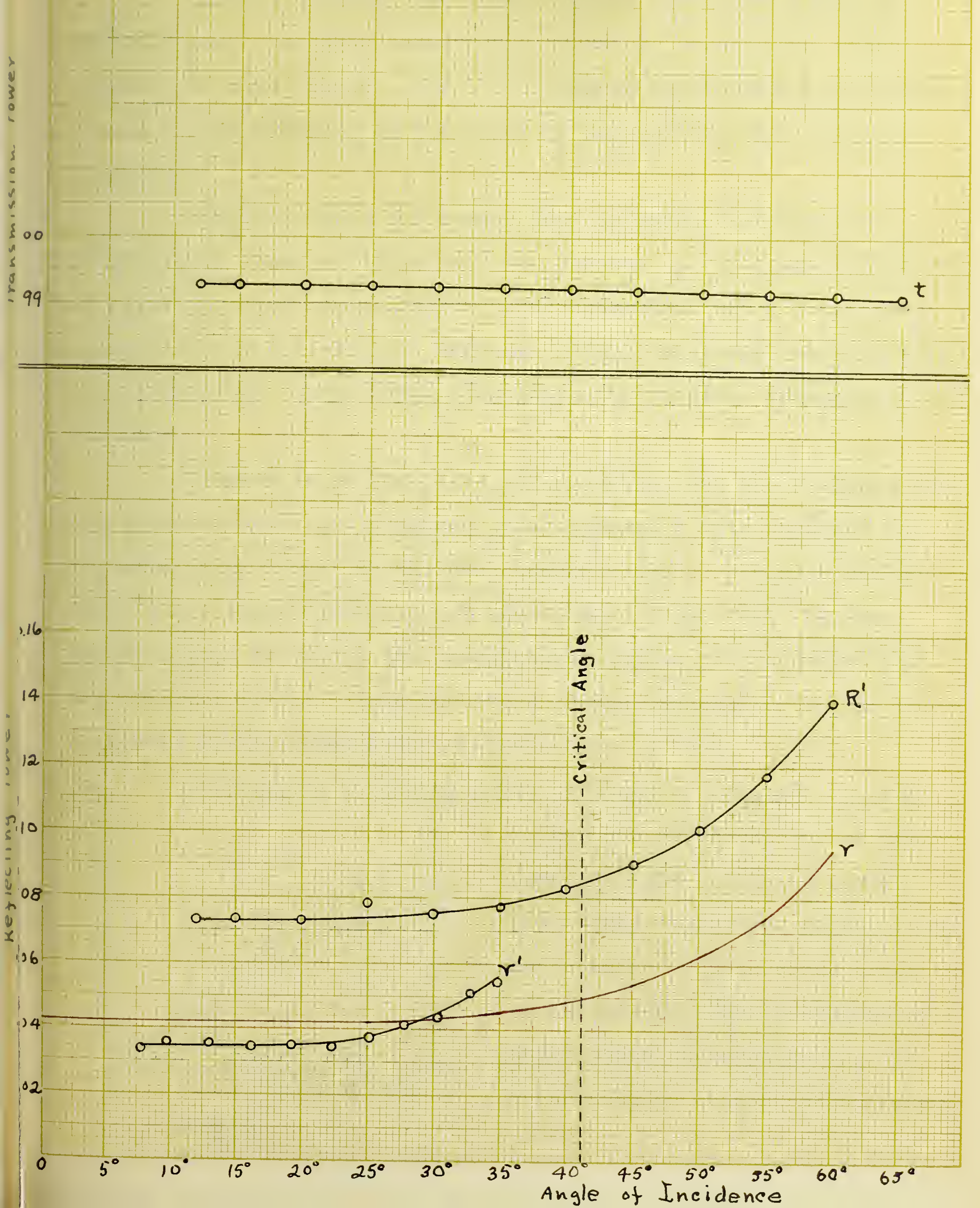
i = angle of incidence.

TABLE III

Angle of Incidence	Thickness of glass d mm.	T	R'	r'	τ	$t = \tau^d$
12°	1.762	0.9200	0.0730	0.0336	0.9951	0.9928
15°	1.763	0.9226	0.0735	0.0358	0.9977	0.9928
20°	1.785	0.9170	0.0729	0.0357	0.9937	0.9927
25°	1.810	0.9165	0.0782	0.0344	0.9969	0.9926
30°	1.842	0.9235	0.0751	0.0349	0.9989	0.9925
35°	1.879	0.9141	0.0773	0.0345	0.9940	0.9923
40°	1.918	0.9137	0.0830	0.0377	0.9963	0.9922
45°	1.967	0.8995	0.0903	0.0413	0.9948	0.9920
50°	2.016	0.8848	0.1012	0.0439		0.9918
55°	2.067	0.8728	0.1178	0.0512		0.9916
60°	2.118	0.8355	0.1400	0.0543		0.9913
65°						0.9910
				Mean	0.9959	

The results for R', r', t and r, are plotted on Plate III. The values of r' are somewhat lower than r, except for values of the angle of incidence approaching the critical angle for the glass plate, when r' crosses r and would ultimately reach 100% for values of the angle of incidence of 41°. (r is replotted in red color)

Plate III


Transmission Power
1.00
.99
t
Reflecting Power
.16
.14
.12
.10
.08
.06
.04
.02
R'
r
r'
Critical Angle
0
5°
10°
15°
20°
25°
30°
35°
40°
45°
50°
55°
60°
65°
Angle of Incidence

VI

Results on Reflecting Power of Potassium, Sodium, and Rubidium

Three K mirrors were investigated. Two were formed by distillation, the third however was formed by pouring the metal against the glass plate. The latter method was rendered quite difficult by the tendency of the metal to crystallize after solidification.

The data taken for mirror No. 1 is given in detail in Table IV, in order to illustrate the various calculations necessary to allow for slow variations in light intensity, and for the deviation of the photo-electric current - light intensity relation from a straight line. This table also shows the possible accuracy to be obtained.

Inspection of the first column shows that the readings for the various angles of incidence were alternated with readings for the beam going direct to the cell (unreflected). The mean deflection in the third column is not more than 0.1 mm. off. In the fourth column are given the extrapolated values of the deflection for the beam direct. This was taken as the deflection for the direct beam during observation on the reflected beam.

The numbers in column 5 are obtained as follows. In Fig. 9, let OCa represent one of the current-light intensity curves previously shown, the galvanometer deflections on this curve being of the order of the galvanometer deflections observed during the determination of reflecting power.

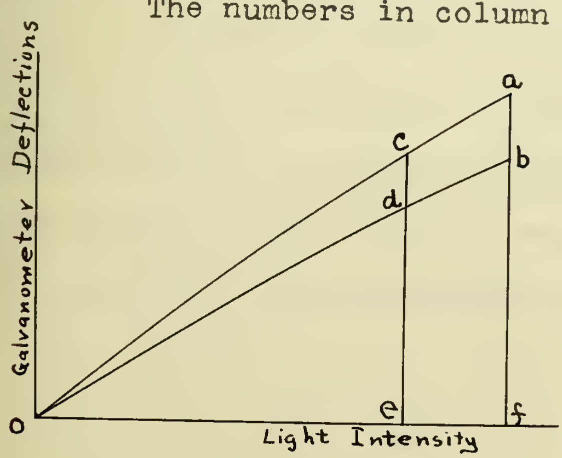


Fig. 9.

Let bf represent one of the values given in the fourth column of Table IV, for the beam going directly to the cell. Also, let de represent the mean deflection (column three) for reflected light. Let af represent the deflection for unit light intensity on one of the photo-electric current - light intensity curves shown on Plate I . By forming the proportion $\frac{af}{bf} = \frac{ce}{de}$ and solving for ce, we arrive at the value of the ordinate on the calibration curve, whose abscissa gives directly the fraction $\frac{O}{I}$, of the incident light that is reflected. For example, taking the second figure in the third column of Table IV, de = 50.37. Corresponding to this, bf = 57.35. Taking the calibration curve whose value for af is 53.55, it follows that ce = 47.0. Referring to the calibration curve, we find that corresponding to 47.0, $\frac{O}{I} = 0.8700$. This method of correcting the observed values in accordance with the calibration curves is quite accurate, since calculations made with the calibration curves previously given, show that the ordinates of the various curves for a given value of the light intensity are very closely proportional to each other.

In the last column of the table are given the values of the R itself calculated from equation (1).

It must be borne in mind that calculations for all reflecting powers were performed in the manner outlined. However, the calculations in all succeeding tables are omitted, since they would only serve to make this presentation unduly bulky without adding in the clearness of the manuscript.

TABLE IV

Potassium Mirror No.1, Formed by Distillation

Angle of Incidence on mirror	Deflections mm.	Mean Deflection (de)	Corresponding value of deflec. for unreflected beam (bf)	Deflection as extrapolated on calibration curve (ce)	$\frac{O}{I}$	R	Angle of Incidence on metal itself. (Cal'd. from Snell's law)
Beam direct	57.1 57.1 57.0	57.07					
15°	50.4 50.5 50.2	50.37	57.35	47.0	0.8700	0.8805	9°50'
Beam direct	57.8 57.5 57.6	57.63					
25°	50.7 50.8 50.5	50.67	58.00	46.8	0.8675	0.880	16°12'
Beam direct	58.4 58.3 58.1 58.3	58.37					
35°	51.0 50.9 51.0	50.97	58.12	46.95	0.8695	0.8815	22°14'
Beam direct	57.9 57.9 57.8	57.87					
45°	50.8 50.7 51.0	50.83	57.8	47.1	0.8720	0.8847	27°49'
Beam direct	57.7 57.7 57.8	57.73					
55°	51.4 51.3 51.3	51.33	58.0	47.43	0.8790	0.8900	32°43'

TABLE IV continued

Angle of Incidence on mirror	Deflections mm.	Mean Deflection (de)	Corresponding value of deflec. for unreflected beam (bf)	Deflection as extrapolated on calibration curve (ce)	O/I	R	Angle of Incidence on metal itself. (Cal'd. from Snell's law)
Beam direct	58.1 58.2 58.4 58.1	58.27					
13°.5	51.0 50.9 50.9	50.93	58.25	46.8	0.8675	0.8760	8°52'
Beam direct	58.3 58.2 58.2	58.23					
20°	50.9 51.0 51.0	50.97	58.23	46.87	0.8690	0.8805	13°3'
Beam direct	58.0 58.4 58.3	58.23					
30°	51.8 52.1 51.9 52.0	51.95	58.03	47.9	0.8880	0.9000	19°16'
Beam direct	58.5 58.3 57.2 57.3	57.83					
40°	51.0 51.3 51.0 52.2 52.0 52.0	51.58	58.23	47.7	0.8850	0.8978	25°6'
Beam direct	58.3 58.5 58.7 58.9 58.7	58.62					

TABLE IV continued

Angle of Incidence on mirror	Deflections mm.	Mean Deflection (de)	Corresponding value of deflec. for unreflected beam (bf)	Deflection as extrapolated on calibration curve (ce)	$\frac{O}{I}$	R	Angle of Incidence on metal itself. (Cal'd. from Snell's law)
50°	52.1 52.0 52.4 51.9 52.4	52.16	58.56	47.7	0.8850	0.8972	30°22'
Beam direct	58.7 58.4 58.4	58.5					
60°	51.5 51.6 51.6	51.57	58.59	47.12	0.874	0.8825	34°51'
Beam direct	58.5 58.6 58.8 58.8	58.68					

In Table V is given a summary of the results obtained for three potassium mirrors. Mirrors No. 1 and 3 were formed by distillation, while No.2 was formed by pouring the molten metal against the glass, and allowing it to solidify.

TABLE V Potassium

O/I					R				
Angle of incidence	No.1	No.2	No.3	Mean	Angle of Incidence on metal	No.1	No.2	No.3	Mean
13°.5	0.8675	0.869	———	0.868	8°52'	0.876	0.878	———	0.877
15°	0.8700	0.8685	0.865	0.868	9°50'	0.8805	0.8795	0.875	0.8785
20°	0.8690	0.869	0.8645	0.8675	13°3'	0.8805	0.8805	0.876	0.879
25°	0.8675	0.8805	0.8685	0.8720	16°12'	0.880	0.8925	0.8805	0.8845
30°	0.8880	0.873	0.875	0.8785	19°16'	0.900	0.8845	0.887	0.8905
35°	0.8695	0.8835	0.863	0.872	22°14'	0.8815	0.8965	0.876	0.8845
40°	0.8850	0.880	0.858	0.8745	25°6'	0.898	0.892	0.869	0.8865
45°	0.8720	0.880	0.860	0.8705	27°49'	0.8845	0.8925	0.872	0.883
50°	0.885	0.887	0.8685	0.880	30°22'	0.897	0.899	0.881	0.8925
55°	0.879	0.875	0.8645	0.873	32°43'	0.890	0.887	0.877	0.8845
60°	0.874	0.880	0.8715	0.8755	34°51'	0.8825	0.890	0.8805	0.8845

The agreement between the reflecting powers for the different mirrors is indeed quite satisfactory considering that the mirrors were made at different times and under different circumstances. Especially is the agreement between mirrors 1 and 2 to be noted. The former being a distilled mirror, the latter being the "solid" metal mirror. This excludes any doubts that the metallic layers of the

distilled mirrors were not thick enough.

The variation of the reflecting power with the angle of incidence is shown on Plate IV. The reflecting powers increase very slowly with the angles of incidence. This is to be expected, since the reflecting powers are so high to start with.

Due to refraction through the glass plates, the actual angles of incidence on the metal are of course less than those on the whole mirror, so that the curves for R are "shrunk" to the left. The critical angle for the glass used is the maximum that could ever be reached using glass plates.

Much greater difficulty was experienced in obtaining a good sodium mirror than in obtaining a potassium mirror, due to the higher distillation point of sodium. Most of the attempts resulted in failures due to a slight impure film forming on the metal next to the glass. This was probably an oxide film, as great care was always taken to clean the glass thoroughly. A mirror was finally however obtained, which showed none of these films and appeared very perfect as viewed with the eye. The results are given in Table VI.

It was impossible to form a solid mirror of Na due to its very great surface tension when in the liquid form, and the ease with which it becomes contaminated.

The increase of reflecting power with increasing angle of incidence is not marked, since the reflecting power of sodium is already very high, and hence there is little room for variation.

TABLE VI Sodium

Angle of Incidence	$\frac{O}{I}$	R	Angle of Incidence on the metal
13°.5	0.8845	0.8950	8° 52'
15°	0.8820	0.8950	9° 50'
20°	0.8825	0.8935	13° 3'
25°	0.8845	0.8975	16° 12'
30°	0.8785	0.8915	19° 16'
35°	0.8945	0.9075	22° 14'
40°	0.8925	0.9052	25° 6'
45°	0.8975	0.9104	27° 49'
50°	0.8870	0.8990	30° 22'
55°	0.8975	0.9090	32° 43'
60°	0.9000	0.9115	34° 51'

No great difficulty was met with in the formation of rubidium mirrors since the metal distills quite easily. The chief difficulty lies in obtaining the pure metal from its chloride. However, Rb is more easily oxidized than Na or K and hence a better vacuum must be insured. The values obtained with a mirror which showed no surface defects is given in Table VII.

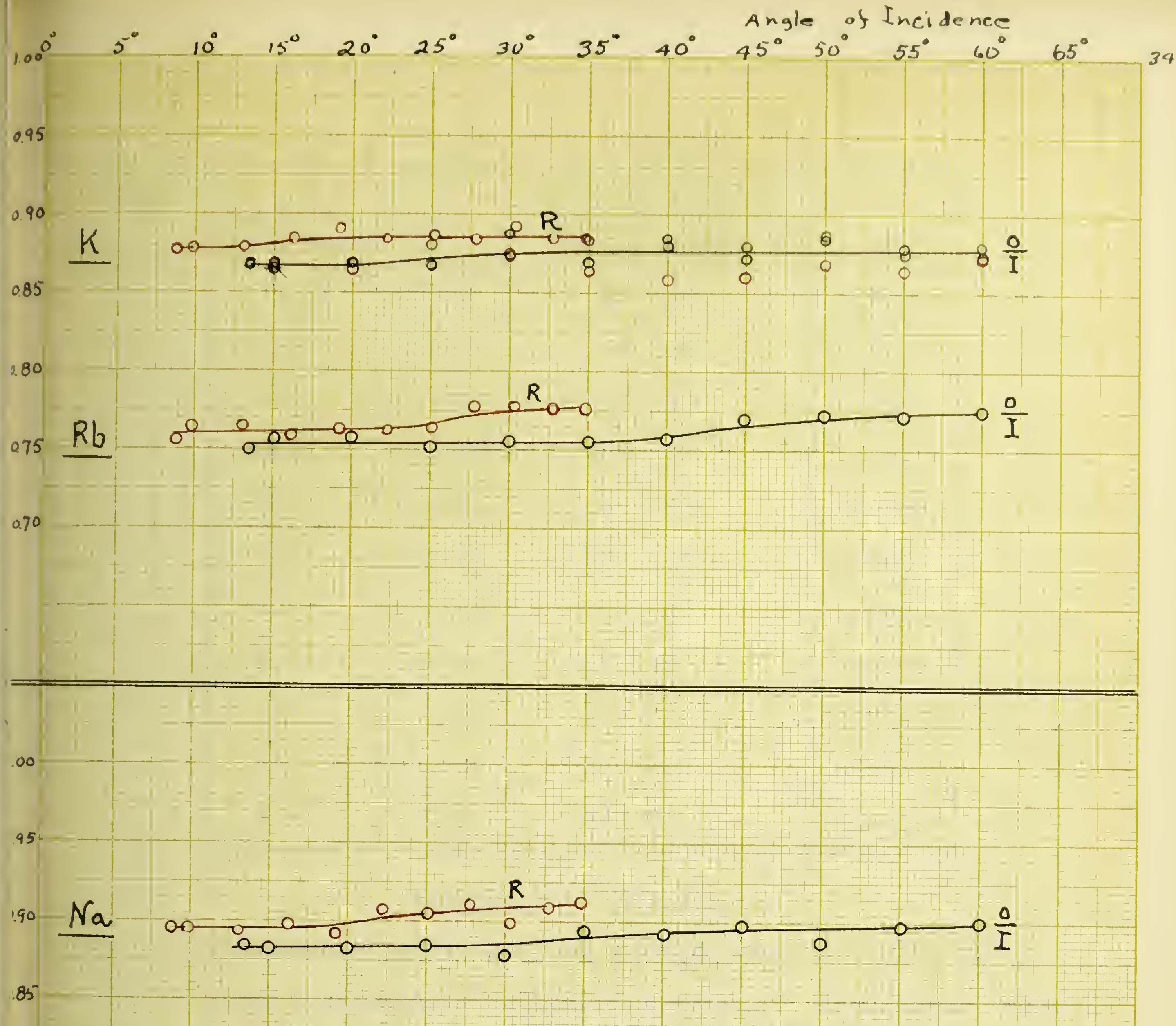


Plate IV

Natural White Light

TABLE VII Rubidium

Angle of Incidence	$\frac{O}{I}$	Angle of Incidence on the metal	R
13°.5	0.750	8° 52'	0.756
15°	0.757	9° 50'	0.764
20°	0.7575	13° 3'	0.765
25°	0.7505	16° 12'	0.758
30°	0.755	19° 16'	0.7626
35°	0.755	22° 14'	0.762
40°	0.7575	25° 6'	0.7645
45°	0.770	27° 49'	0.7775
50°	0.7725	30° 22'	0.7777
55°	0.7707	32° 43'	0.776
60°	0.775	34° 51'	0.7755

Discussion of Results

The values for Na are not plotted next to those for K in order to avoid confusion of contiguous points. In general, the reflecting power rises slowly with the angle of incidence. The reflecting power is at first quite constant, then suffers a rather rapid rise, and then is nearly constant again. The values for the reflecting powers of the metals themselves are about one per cent higher than those for the whole mirror.

Na has the highest reflecting power, K being almost as good. Rb is less than K, so that the reflecting powers increase as the atomic weight decreases.

PART II

Monochromatic, Polarized Light

I- Arrangement of Apparatus

The Source of Light:- In this part of the work, it was proposed to investigate the reflecting powers of Na, K and Rb for polarized monochromatic light. The arrangement of apparatus is shown in Fig. 10. In Part I, a Nernst glower was used as a source of light. Its use, however was unsatisfactory, since it decreased so rapidly in efficiency due to the polarization of the filament on direct current. The alternating current could not be used since it was too unsteady. Consequently for this part of the investigation, a 250 watt, nitrogen filled, tungsten projection lamp was employed.

The Optical System:- The light from one of the filaments, S, was focused upon the slit of the collimator, C, after passing through the system of condensing lenses. The focal length of the collimator was so adjusted that the emergent rays were just slightly convergent, the light being focused about 1 1/2 meters away upon the photo-electric cell. The central portion of the beam emerging from the collimating lens was allowed to pass through a good dispersing prism P, the spectrum being spread out over E. The source of light condensing lenses and prism were mounted on a moveable table which could be rotated about an axis A through the center of the prism. Hence, by rotating this table any portion of the spectrum could be thrown upon the aperture E.

The light after passing through the rectangular Nicols, N_1 and N_2 and through the narrow slit H(7 x 1 mm.), was incident directly upon the photo-electric cell, or else after reflection at the mirror M. The Nicols served a double purpose, both for plane

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[illegible]

[illegible]

[illegible]

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Arrangement of Apparatus for Monochromatic Polarized Light.

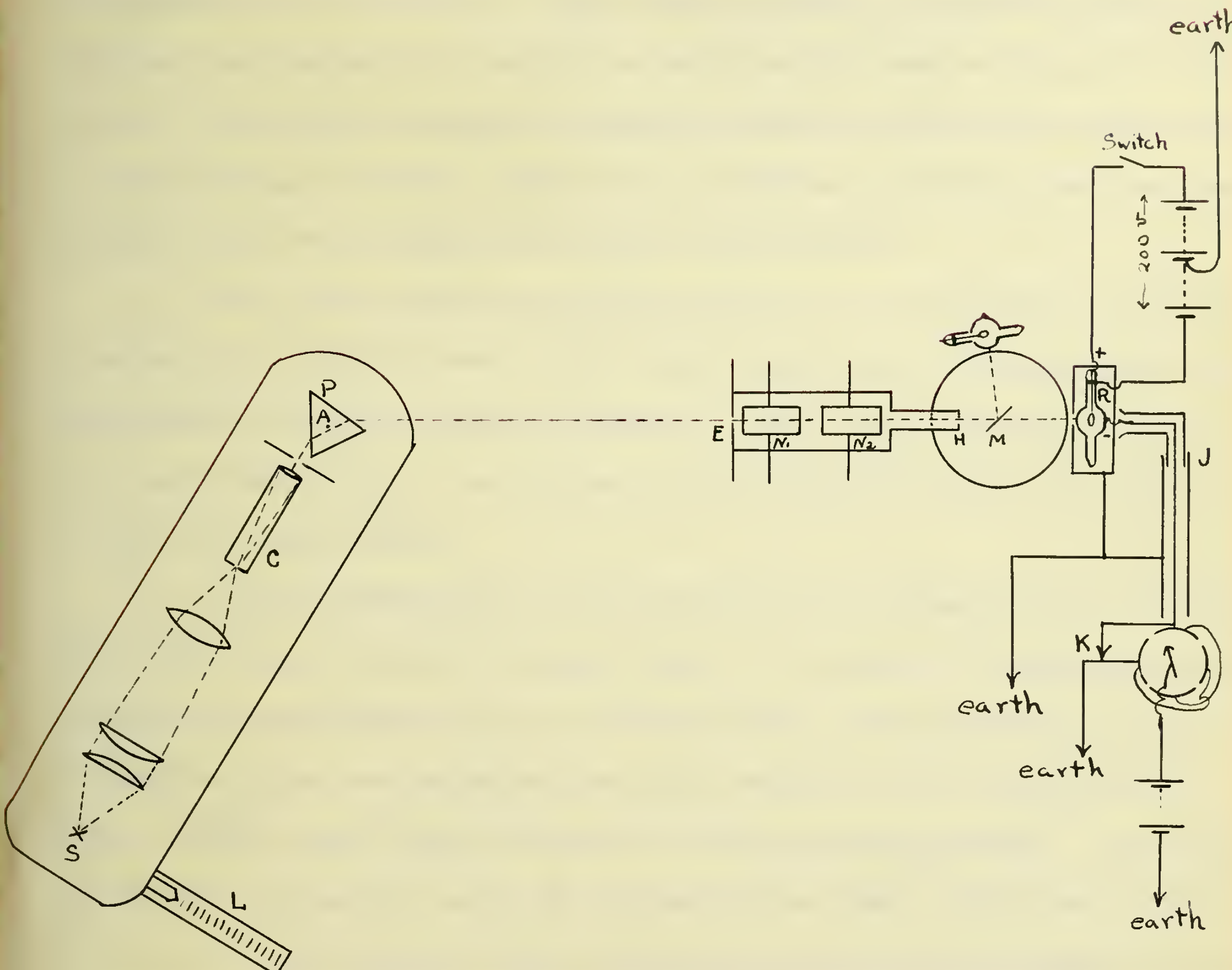

Fig. 10

polarizing the light, and for calibration of the photo-electric currents in terms of known light intensities.

The photo-electric cell was used in connection with the spectrometer as in Part I. The tube enclosing the Nicols and containing the aperture H, served to exclude extraneous light from the source. This tube was made purposely narrow towards the end so as to make the use of small angles of incidence possible when the photo-electric cell was swung around the spectrometer.

All light from extraneous sources was completely excluded by means of a double heavy cloth hung all around the apparatus, the room itself being partially darkened. That the screening was perfect was shown by the zero photo-electric current when the shutter of the cell was opened.

During observation on reflection, the Nicols were arranged with their axes parallel to each other. In order to determine their planes of polarization, N_1 was removed and a glass plate of known refractive index was mounted over the center of the spectrometer table, so that the light was incident at the polarizing angle. By placing the eye along the path of the reflected beam, and then rotating N_2 slowly, a position for the latter was soon reached where the reflected light was reduced to a minimum which was nearly zero. The plane of polarization of N_2 was then known to be perpendicular to the plane of incidence. The plane of polarization of N_1 was then easily determined by reference to N_2.

It may be said in passing that complete extinction of the polarized light by means of the glass plate was impossible. This was doubtless due to the slight ellipticity[14] of the light in the

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14 Drude's Theory of Optics, p.294, (English translation)

neighborhood of the polarizing angle.

Calibration of Apparatus in Terms of Wave Lengths

This calibration was effected by means of a Hilger wave length spectrometer. The instrument was first adjusted using the hydrogen red and blue lines. The collimator of the instrument was then placed opposite H in the position occupied by the photo-electric cell. It was found that the incident light was not purely monochromatic, the light as viewed through the Hilger spectrometer being somewhat drawn out in the form of a band. A rapid test of the reflecting power of an alkali metal as a function of the wave length showed that the variation was quite small, hence it was unnecessary to have absolutely pure monochromatic light.

The cross hair of the Hilger eye piece was accordingly set on the middle of the bright band in the calibration, so that the value of the wavelength as read represented the mean wave length for that position of the optical table. The scale L, was thus calibrated in terms of mean wave lengths of light.

The Electrometer:- Since the light intensities incident on the photo-electric cell are much smaller than in the case of white light, it was decided to use an electrometer to measure the photo-electric currents. The electrometer was of the Cambridge Scientific type, giving a deflection of about 200 mm. at a distance of 2.3 meters for a difference of 1.5 volts between the 2 pairs of quadrants, there being 96 volts on the needle. The electrometer was placed in a fairly air tight tin box which was well earthed to a water pipe.

One pair of quadrants was always left earthed, the other pair (which could also be earthed) was connected to the cathode of

the photo-electric cell. The latter connection was affected through a wire which was completely protected from outside disturbing influences by running the wire through a glass tube, the outside of which was wrapped in tin foil and well earthed. This protection for the wire was found to be absolutely necessary. A loose joint, J, permitted the motion of the photo-electric cell about the spectrometer. The earthing of the pair of quadrants connected to the cell, was done by means of the electrometer key, K, consisting of a sharp brass pointed rod, R, dropping on a brass plate, P. The rod could be raised or lowered by means of the cord C, leading to the observer, by means of pulleys.

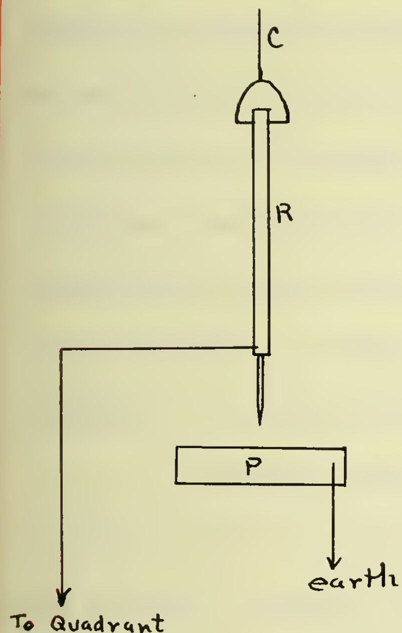


Fig. 11.

The needle of the electrometer was carefully insulated by means of amber, so that under ordinary working conditions, no leakage could be observed when the quadrants were charged to a difference of potential. There was, however, a slow drift in the direction of an increasing deflection, which proved quite troublesome. This seemed to be clearly due to a "dark current" or a leakage current across the glass of the photo-electric cell, not withstanding the prsence of the earthed ring between anode and cathode. However, by putting this ring at a potential of about 200 volts below that of the anode, the drift was completely eliminated.

The voltage employed across the cell varied from 80 to 120 volts, the negative pole of the battery being earthed as shown in

Fig. 10.

II. Method of Observation

The electrometer was used "ballistically", i.e., the photo-electric cell was exposed to the light for a definite short interval, and either the resulting steady deflection or "first throw" of the needle noted. The time interval was given by a metronome adjusted to beat (approximately) seconds. The shutter of the cell, as in Part I, could be operated by the observer at his observing post at the telescope. At the beat of the ticker, the shutter could be "snapped up" and then smartly closed at the end of the chosen time interval. Proper weighting of the cord ensured the smooth working of the shutter, and after some practice, the time length of exposure could be made to a tenth of a second.

Towards the latter part of this investigation, the humidity of the spring air made it difficult for the electrometer to hold its charge, so that instead of waiting for the needle to come to rest, and noting the steady deflection, the first throw of the needle was taken. It was found that not only was the accuracy of observation not marred by this procedure, but that furthermore, double the number of observations could be taken in a given time interval.

Light of a known mean wave length polarized either parallel or perpendicular to the plane of incidence was allowed to fall on the shutter of the photo-electric cell. The electrometer key was opened, and when the needle had come to rest, the cell was exposed to the light for 10 or 15 sec., and the steady deflection or else the first throw noted. The deflection for the reflected light was then taken, and then the deflection for the beam direct in accordance with the method outlined in Part I. Deflections varying from

50 to 200 mm. were employed.

In order to calibrate the observed deflections in terms of known light intensities, keeping conditions the same as before the Nicol N_1 was rotated through various angles. Observations were taken in adjacent quadrants and the mean taken to correct for any asymetry of the Nicols with respect to the axis of rotation. These mean deflections were then plotted against the squares of the cosines of the angles. The light intensities corresponding to the observed deflections for the reflected light could then be read on the curve, giving the reflecting powers directly. A calibration curve was thus obtained for every series of observations.

The true relation between the light intensity and photo-electric current can only be determined under the imposition of proper experimental conditions. In the present investigation, the interest lay not so much in the relation between the current and the light intensity, as in the relation between the light intensity and resulting electrometer deflections. Experimental conditions were always employed such as to give greater stability and accuracy to the observations. Consequently as low voltage as possible was used on the needle. Also in part of the work as previously mentioned the first throw of the needle was employed.
For these reasons, it is not safe to assume that the photo-electric current is proportional to the electrometer deflections. Hence the curves between electrometer deflections and light intensity are not to be assumed as being relations between photo-electric current and light intensity. They are merely to be regarded as calibration curves. In general the curves approximated to straight lines, being either slightly convex or concave to the illumination axis,

depending upon the experimental conditions imposed. Since no theoretical value is assigned to these curves, consequently they are omitted. It must be remembered, however, that the curves given in Part I are true current-light intensity curves.

III Optical Properties of the Glass Plates

In Part I it was shown that the reflecting power of the metal itself is only slightly different from that of the mirror as a whole, the former being only from a fraction to a little over one per cent greater than the latter. Since the correction is only a small one, it was deemed inadvisable to make exhaustive studies on the optical properties of the glass plates. Accordingly the values given in this part of the work are a good approximation to the actual values, but are not as accurate as those obtained in Part I.

In Part I, it was shown that within experimental errors, Fresnel's reflection equations hold for the front face of the glass. Hence the values for r were calculated from the equations

$$r = \frac{\sin^2(i-\theta)}{\sin^2(i+\theta)} \qquad \text{and} \qquad r = \frac{\tan^2(i-\theta)}{\tan^2(i+\theta)}$$

for light polarized parallel and perpendicular to the plane of incidence, respectively.

The values of the index of refraction of the glass plates for the wave lengths used are given in Table VIII. They were obtained by means of the Abbe refractometer using the method of grazing incidence.

TABLE VIII

	λ ($\mu\mu$)	n
red	640.9	1.5132
yellow	589.3	1.5151
green	539.6	1.5181
blue	488.8	1.5212
violet	454.6	1.5252

The variation of r with the wave length is rather small (0.2% over the range employed), since the variation in n is small, the range of wave lengths extending from about 450.0 to 650.0 $\mu\mu$. The values of r for yellow light are plotted on Plate V.

The range of wave lengths used being in the visible portion of the spectrum, it could be "a priori" assumed that the transmission power of the glass for the different colors would be the same as for white light, since no dispersion or color effects are ever visible to the eye upon looking through the glass. Nevertheless, it was decided to test out this point by a short method.

Light polarized perpendicular to the plane of incidence was incident on the glass plate at the polarizing angle. Very little light was thus reflected, practically all being transmitted. Hence, the transmission power of the glass for that angle could be obtained by subtracting the transmitted from the incident light, allowing a small correction for the slight amount of reflected light.

Tests with various colors, showed absence of any variation in the transmission power, the values for t being of the order given in Part I. As a result the values for t given in Part I were taken for this part of the work.

The values for r' (reflecting power of internal face of glass) for green light, taken for several angles of incidence are given in Table IX. The other values were taken from the curves shown on Plate V. These values for r' were used for all the colors. This use of r' is, however, not as radical as it might appear. In the first place, r varies very slowly with wave length, hence, the variation in r' must be likewise very small. Secondly, let us

consider the equation for R in the form,

$$R = \frac{\frac{O}{I} - r}{t^2\left\{1 - r'(1-\frac{O}{I})-r\right\}}$$

The values of $\frac{O}{I}$ vary from 0.8 to 0.95. $1 - \frac{O}{I}$ is therefore a very small fraction, as well as r'. Consequently $r'(1-\frac{O}{I})$ is very small compared to 1-r, so that an error in r' even to the extreme extent of 5%, could only result in an error of 0.1 or 0.2% in the final values of R.

Inspection of the curves for r' shows that for small angles of incidence r' is less than r, but rises above r for angles of incidence approaching the critical angle at 41°. This rise is especially rapid in the case of light polarized parallel to the plane of incidence.

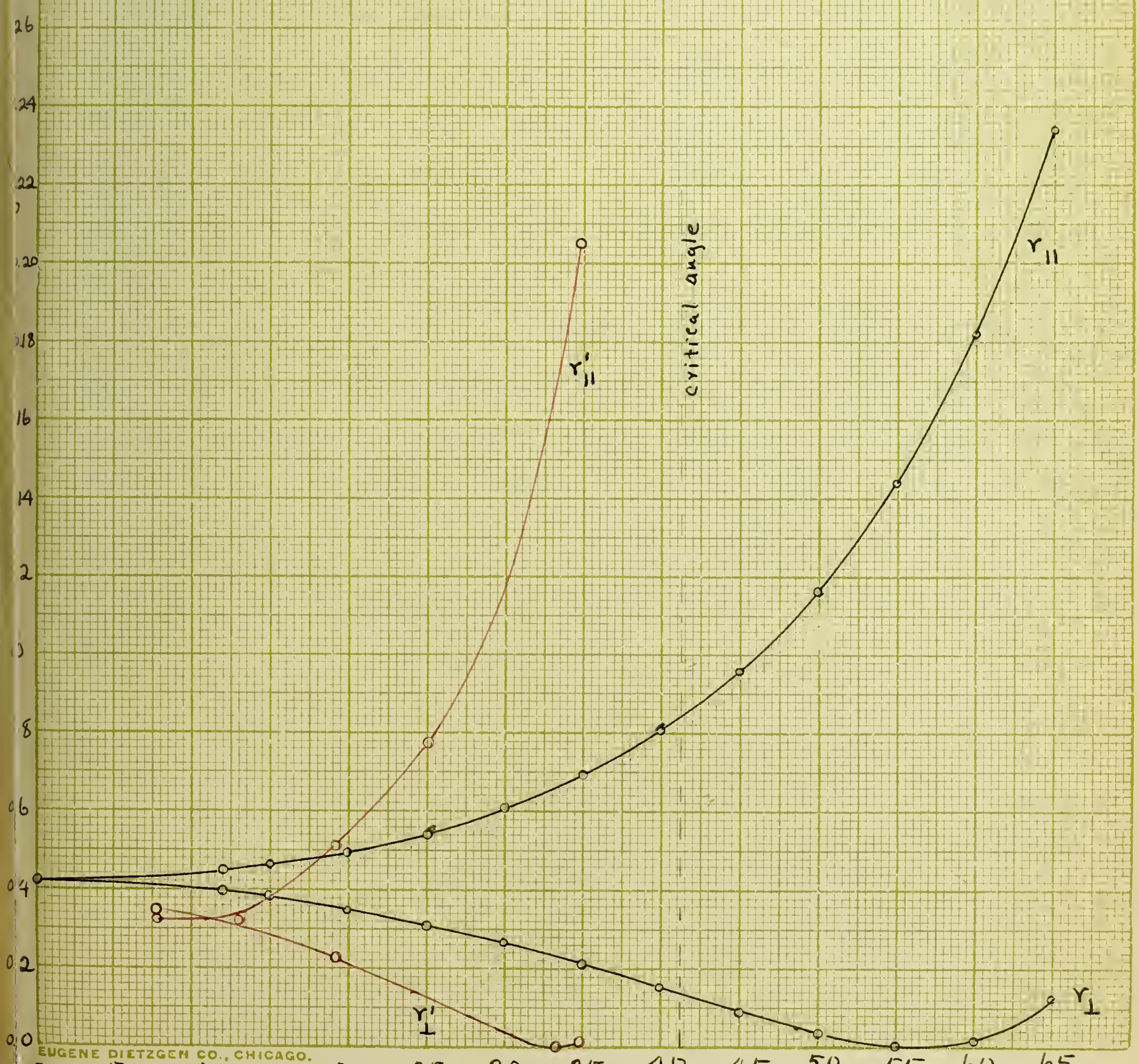
TABLE IX

Values of r' for λ = 539.6 $\mu\mu$ (1 $\mu\mu$ = 10^{-7} cm.)

Internal Angle of Incidence	Plane of Polarization ‖ to plane of Incidence	Plane of Polarization ⊥ to Plane of Incidence
7° 53'	0.0324	0.0350
13° 2'	0.0322	———
19° 14'	0.0511	0.0224
25° 3'	0.0774	———
33° 23'	———	0.0000
34° 51'	0.2050	0.0010

Plate V

Reflecting Power of Internal and Front Faces of Glass Plate, for Light polarized Parallel and Perpendicular to the Plane of Incidence.



IV Results

The reflecting powers of potassium, sodium and rubidium are given in the following tables and curves. The symbols || and $\perp$ on the curves indicate that the plane of polarization is parallel or perpendicular to the plane of incidence, respectively. In general, the reflecting powers are somewhat higher than those obtained in Part I for white, unpolarized light. The curves are similar to those obtained for a transparent medium, i.e., the reflecting power for light polarized parallel to the plane of incidence increases steadily with increased angle of incidence, while for light polarized perpendicular to the plane of incidence, the reflecting power decreases with increased angle of incidence. In the latter case the minimum value reached would of course not be equal to zero as in the case, e.g., of glass.

The curves for K are not as smooth as those for Na and Rb, due to the fact that the steady deflection method was used in the case of K, while the method of first throw was used in the case of Na and Rb. Furthermore, nearly all of the points for Na and Rb are the mean of two values. Na has on the grand average just a slightly better reflecting power than K, Rb being less than either as in Part I.

TABLE X

Reflecting Power ($\frac{O}{I}$) of K Mirror No.2

(Metal Faced with Glass)

Plane of Polarization Parallel to Plane of Incidence

Angle of Incidence	λ in μμ 640.9	589.3	539.6	488.8	454.6
12°	0.905	0.921	0.917	0.912	0.900
20°	0.933	0.914	0.936	0.932	0.940
25°	0.949	0.903	———	0.932	———
30°	0.935	0.898	0.925	0.930	0.889
40°	0.958	0.926	0.937	0.915	0.929
50°	0.950	0.921	0.940	0.935	0.940
60°	0.956	0.916	0.937	0.935	0.898
65°	0.965	0.920	0.937	0.959	0.954

Plane of Polarization Perpendicular to Plane of Incidence

12°	0.935	0.914	0.908	0.902	0.902
15°	0.915	0.922	———	———	0.881
20°	0.934	0.926	0.896	0.919	0.890
30°	0.905	0.925	0.918	0.902	0.880
40°	0.941	0.925	0.907	0.910	0.883
50°	0.926	0.895	0.911	0.919	0.886
60°	0.920	0.930	0.905	0.931	0.885
65°	0.923	———	———	———	0.894

TABLE XI

Reflecting Power (R) of K No.2

Plane of Polarization Parallel to Plane of Incidence

λ in μμ

Angle of Inc.	λ 640.9	Angle of Inc.	λ 589.3	Angle of Inc.	λ 539.6	Angle of Inc.	λ 488.8	Angle of Inc.	λ 454.6
7°54'	0.917	7°53'	0.934	7°53'	0.929	7°52'	0.923	7°50'	0.910
13° 4'	0.945	13° 3'	0.924	13° 2'	0.949	13° 0'	0.944	12°58'	0.950
16°13'	0.963	16°12'	0.913	16°10'	——	16° 8'	0.945	16° 5'	——
19°18'	0.948	19°16'	0.911	19°14'	0.938	19°11'	0.943	19° 8'	0.901
25° 8'	0.973	25° 6'	0.942	25° 3'	0.952	25° 0'	0.930	24°56'	0.943
30°25'	0.967	30°22'	0.936	30°18'	0.955	30°14'	0.951	30° 9'	0.956
34°55'	0.973	34°51'	0.931	34°47'	0.954	34°42'	0.953	34°36'	0.914
36°48'	0.983	36°44'	0.940	36°39'	0.956	36°34'	0.976	36°27'	0.972

Plane of Polarization Perpendicular to Plane of Incidence

Angle of Inc.	λ 640.9	Angle of Inc.	λ 589.3	Angle of Inc.	λ 539.6	Angle of Inc.	λ 488.8	Angle of Inc.	λ 454.6
7°54'	0.948	7°53'	0.925	7°53'	0.920	7°52'	0.913	7°50'	0.914
9°50'	0.929	9°49'	0.935	9°48'	——	9°47'	——	9°46'	0.892
13° 4'	0.947	13° 3'	0.940	13° 2'	0.909	13° 0'	0.931	12°58'	0.902
19°18'	0.918	19°16'	0.938	19°14'	0.932	19°11'	0.914	19° 8'	0.893
25° 8'	0.958	25° 6'	0.939	25° 3'	0.922	25° 0'	0.924	24°56'	0.897
30°25'	0.941	30°22'	0.909	30°18'	0.925	30°14'	0.934	30° 9'	0.900
34°55'	0.936	34°51'	0.946	34°47'	0.921	34°42'	0.946	34°36'	0.900
36°48'	0.940	36°44'	——	36°39'	——	36°34'	——	36°27'	0.909

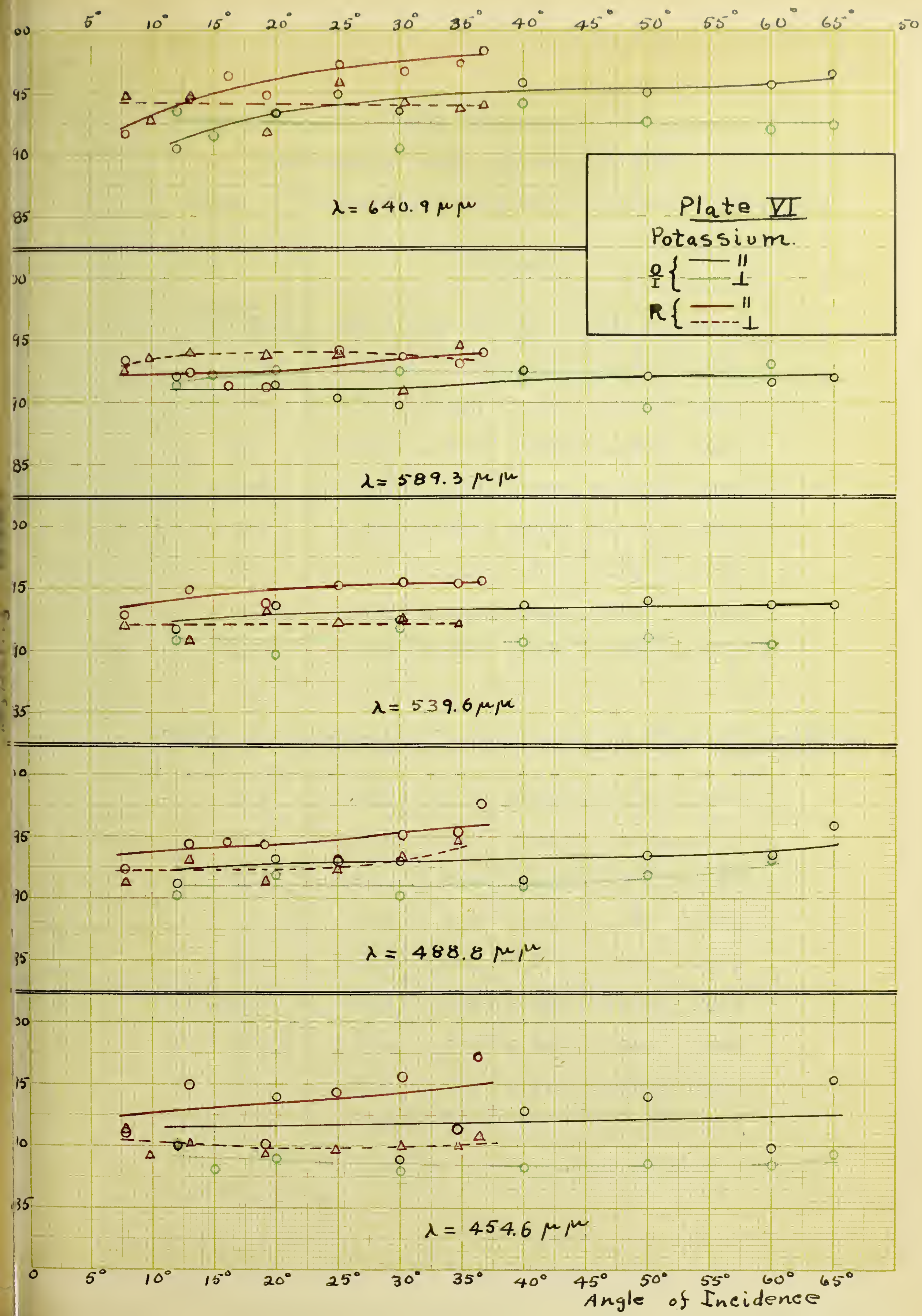


Plate VI
Potassium.
$\frac{O}{I}$ { —— ‖ , —— ⊥
R { —— ‖ , ------ ⊥
λ = 640.9 μμ
λ = 589.3 μμ
λ = 539.6 μμ
λ = 488.8 μμ
λ = 454.6 μμ
0 5° 10° 15° 20° 25° 30° 35° 40° 45° 50° 55° 60° 65°
Angle of Incidence

TABLE XII

Reflecting Power ($\frac{O}{I}$) of Na Mirror

Plane of Polarization Parallel to Plane of Incidence

Angle of Incidence	λ in μμ				
	640.9	589.3	539.6	488.8	454.6
12°	0.936	0.916	0.925	0.917	0.896
20°	0.955	0.925	0.928	0.927	0.898
25°	0.961	0.928	0.933	0.920	0.900
30°	0.957	0.930	0.936	0.932	0.900
40°	0.963	0.931	0.938	0.915	0.907
50°	0.949	0.933	0.933	0.934	0.909
60°	0.957	0.935	0.939	0.933	0.918
65°	0.968	0.947	0.935	0.933	0.914

Plane of Polarization Perpendicular to Plane of Incidence

12°	0.927	0.913	0.927	0.907	0.908
20°	0.936	0.907	0.927	0.916	0.915
25°	0.930	0.915	0.928	0.910	0.909
30°	0.936	0.915	0.924	0.899	0.880
40°	0.913	0.905	0.915	0.897	0.901
50°	0.929	0.903	0.923	0.910	0.886
60°	0.930	0.900	0.921	0.890	0.888
65°	0.931	0.902	0.917	0.898	0.890

TABLE XIII

Reflecting Power (R) of Na.

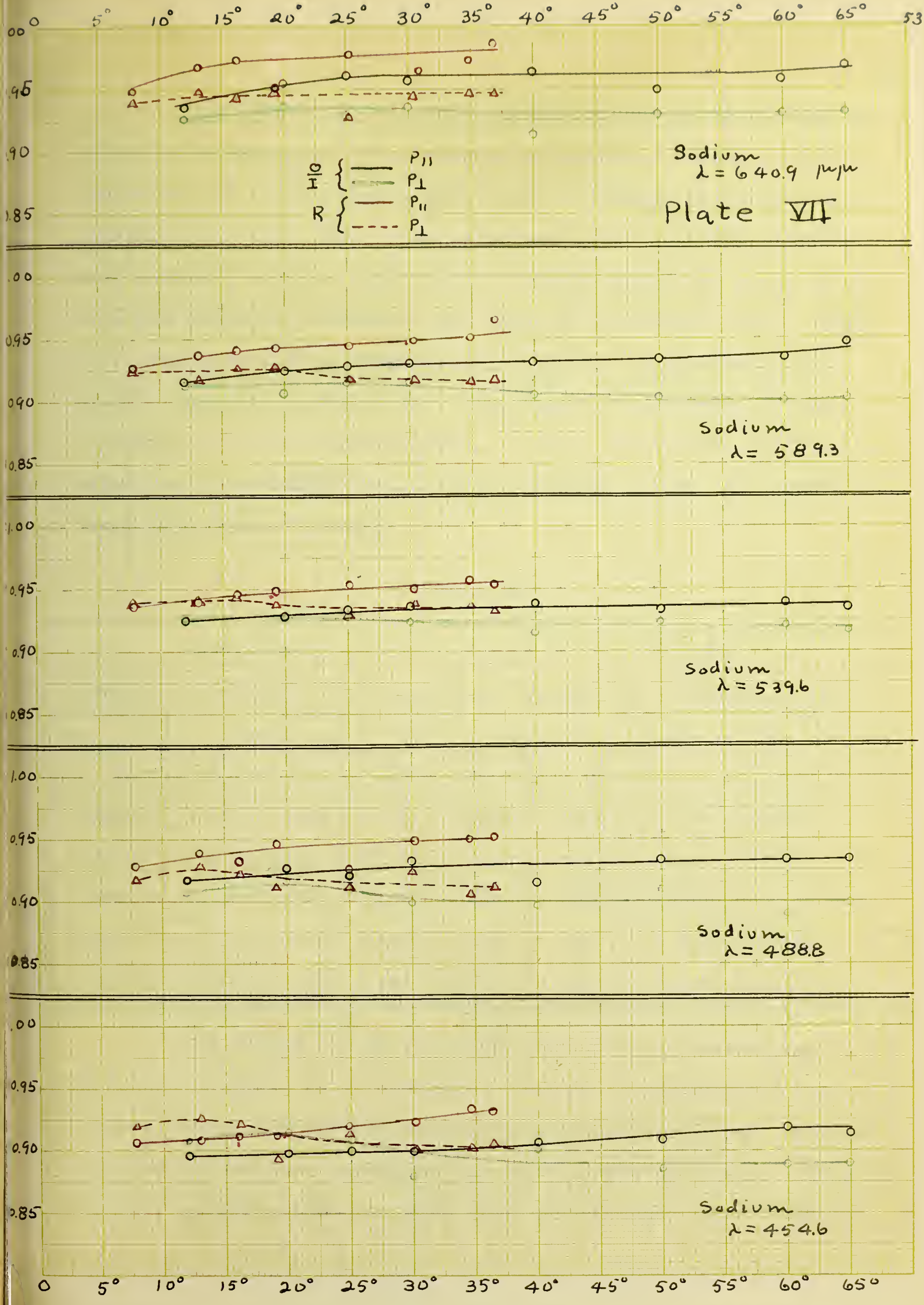
Plane of Polarization Parallel to Plane of Incidence

λ in μμ

Angle of Inc.	λ 640.9	Angle of Inc.	λ 589.3	Angle of Inc.	λ 539.6	Angle of Inc.	λ 488.8	Angle of Inc.	λ 454.6
7°54'	0.949	7°53'	0.927	7°53'	0.936	7°52'	0.928	7°50'	0.907
13° 4'	0.968	13° 3'	0.937	13° 2'	0.940	13° 0'	0.939	12°58'	0.909
16°13'	0.974	16°12'	0.941	16°10'	0.946	16° 8'	0.932	16° 5'	0.912
19°18'	0.952	19°16'	0.943	19°14'	0.949	19°11'	0.946	19° 8'	0.913
25° 8'	0.978	25° 6'	0.945	25° 3'	0.953	25° 0'	0.925	24°56'	0.920
30°25'	0.965	30°22'	0.949	30°18'	0.950	30°14'	0.949	30° 9'	0.923
34°55'	0.973	34°51'	0.951	34°47'	0.957	34°42'	0.950	34°36'	0.934
36°48'	0.986	36°44'	0.965	36°39'	0.953	36°34'	0.951	36°27'	0.932

Plane of Polarization Perpendicular to Plane of Incidence

7°54'	0.940	7°53'	0.925	7°53'	0.940	7°52'	0.919	7°50'	0.920
13° 4'	0.949	13° 3'	0.919	13° 2'	0.940	13° 0'	0.928	12°58'	0.927
16°13'	0.943	16°12'	0.927	16°10'	0.943	16° 8'	0.922	16° 5'	0.922
19°18'	0.949	19°16'	0.928	19°14'	0.938	19°11'	0.911	19° 8'	0.893
25° 8'	0.927	25° 6'	0.918	25° 3'	0.929	25° 0'	0.911	24°56'	0.914
30°25'	0.943	30°22'	0.916	30°18'	0.938	30°14'	0.924	30° 9'	0.901
34°55'	0.946	34°51'	0.915	34°47'	0.936	34°42'	0.906	34°36'	0.903
36°48'	0.946	36°44'	0.917	36°39'	0.932	36°34'	0.912	36°27'	0.906


Sodium
λ = 640.9 μμ
Plate VII
$\frac{O}{I}$ { $P_{\parallel}$ $P_{\perp}$
R { $P_{\parallel}$ $P_{\perp}$
Sodium
λ = 589.3
Sodium
λ = 539.6
Sodium
λ = 488.8
Sodium
λ = 454.6
0 5° 10° 15° 20° 25° 30° 35° 40° 45° 50° 55° 60° 65°
1.00 0.95 0.90 0.85

The values for Na and K compare favorably with those obtained by Duncan using the indirect or katopric method. Direct comparison of these results with those of Duncan is, however, not possible since the light used by Duncan is of slightly different wave lengths, and was polarized in a plane making an angle of 45° with the plane of incidence, the angle of incidence itself being 45°. For convenience, however, the results are included with Duncan's results in Table XIV. The angle of incidence is the closest to 45° that was employed. It will be noticed that my results for K are higher but that the results for Na are somewhat lower than those of Duncan.

TABLE XIV

Nathanson					Duncan		
Angle of Incidence = 36° (approx)					Angle of Incidence = 45°		
	Na		K			Na	K
λ	$\parallel$	$\perp$	$\parallel$	$\perp$	λ		
640.9	0.986	0.946	0.983	0.940	665.0	0.977	0.938
589.3	0.965	0.917	0.940	0.935	589.3	0.971	0.920
539.6	0.953	0.932	0.956	0.921	546.0	0.965	———
488.8	0.951	0.912	0.976	0.946	472.0	0.952	0.869
454.6	0.932	0.906	0.972	0.909	435.0	0.948	———

The curves for Na for light polarized perpendicular to the plane of incidence are noteworthy. For small angles of incidence, the reflecting power first increases and then decreases. This appears to become more marked as the wave length decreases. This is the only evidence that has been obtained that may throw light on

the selective photo-electric effect as depending upon the optical properties of the metals.

The Rb curves also show similar evidence, though not as marked as in Na.

TABLE XV

Reflecting Power $(\frac{O}{I})$ of Rb Mirror No.2

Plane of Polarization Parallel to Plane of Incidence

Angle of Incidence	λ in μμ				
	640.9	589.3	539.6	488.8	454.6
12°	0.852	0.821	0.826	0.812	0.804
20°	0.844	0.820	0.820	0.815	0.805
25°	0.828	0.828	0.825	0.824	0.805
30°	0.870	0.829	0.820	0.837	0.809
40°	0.873	0.845	0.860	0.833	0.823
50°	0.875	0.849	0.828	0.864	0.845
60°	0.872	0.868	0.863	0.875	0.865
65°	0.888	0.868	0.868	0.872	0.860

Plane of Polarization Perpendicular to Plane of Incidence

12°	0.808	0.777	0.790	0.802	0.759
20°	0.813	0.794	0.793	0.776	0.753
25°	0.792	0.788	0.788	0.783	0.764
30°	0.822	0.775	0.800	0.773	0.748
40°	0.785	0.769	0.782	0.770	0.739
50°	0.797	0.765	0.760	0.769	0.750
60°	0.787	0.762	0.793	0.780	0.766
65°	0.790	0.761	0.775	0.783	0.756

TABLE XVI

Reflecting Power (R) of Rb No.2

Plane of Polarization Parallel to Plane of Incidence

λ in $\mu\mu$

Angle of Inc.	λ 640.9	Angle of Inc.	λ 589.3	Angle of Inc.	λ 539.6	Angle of Inc.	λ 488.8	Angle of Inc.	λ 454.6
7°54'	0.862	7°53'	0.831	7°53'	0.835	7°52'	0.821	7°50'	0.812
13° 4'	0.854	13° 3'	0.829	13° 2'	0.830	13° 0'	0.824	12°53'	0.813
16°13'	0.838	16°12'	0.837	16°10'	0.835	16° 8'	0.834	16° 5'	0.813
19°18'	0.881	19°16'	0.838	19°14'	0.831	19°11'	0.847	19° 8'	0.818
25° 8'	0.885	25° 6'	0.855	25° 3'	0.872	25° 0'	0.843	24°56'	0.833
30°25'	0.888	30°22'	0.863	30°18'	0.841	30°14'	0.875	30° 9'	0.857
34°55'	0.887	34°51'	0.883	34°47'	0.877	34°42'	0.891	34°36'	0.878
36°48'	0.904	36°44'	0.882	36°39'	0.884	36°34'	0.888	36°27'	0.874

Plane of Polarization Perpendicular to Plane of Incidence

7°54'	0.818	7°53'	0.785	7°53'	0.799	7°52'	0.811	7°50'	0.766
13° 4'	0.823	13° 3'	0.803	13° 2'	0.802	13° 0'	0.785	12°53'	0.760
16°13'	0.802	16°12'	0.798	16°10'	0.798	16° 8'	0.792	16° 5'	0.771
19°13'	0.833	19°16'	0.785	19°14'	0.810	19°11'	0.783	19° 8'	0.756
25° 8'	0.797	25° 6'	0.780	25° 3'	0.793	25° 0'	0.780	24°56'	0.748
30°25'	0.809	30°22'	0.778	30°18'	0.771	30°14'	0.780	30° 9'	0.760
34°55'	0.801	34°51'	0.776	34°47'	0.805	34°42'	0.794	34°36'	0.778
36°48'	0.803	36°44'	0.773	36°39'	0.788	36°34'	0.796	36°27'	0.769

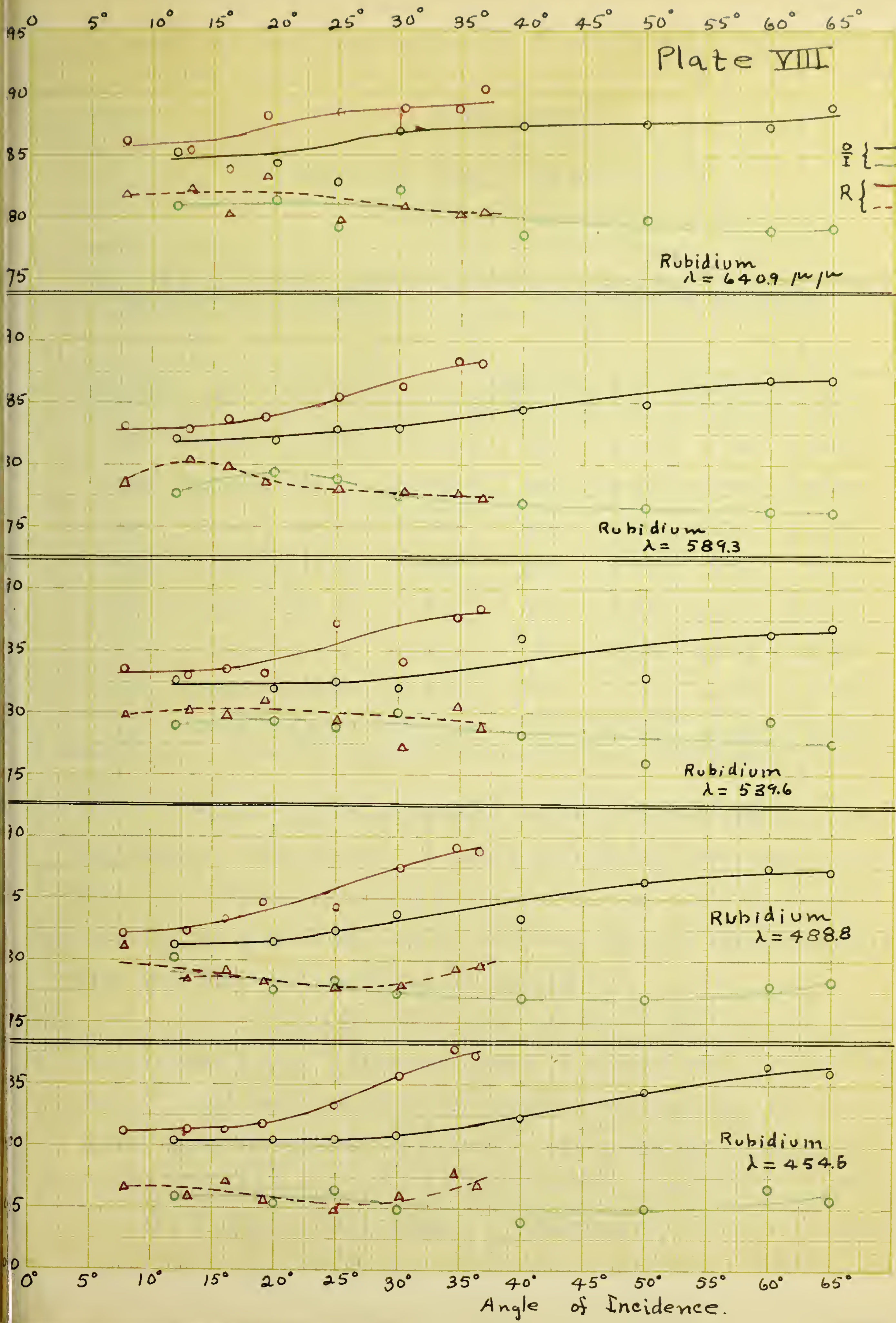


Plate VIII
$\frac{O}{I}$ { — $P_{\parallel}$ — $P_{\perp}$
R { — $P_{\parallel}$ ---- $P_{\perp}$
Rubidium
λ = 640.9 μμ
Rubidium
λ = 589.3
Rubidium
λ = 539.6
Rubidium
λ = 488.8
Rubidium
λ = 454.6
0° 5° 10° 15° 20° 25° 30° 35° 40° 45° 50° 55° 60° 65°
Angle of Incidence.

TABLE XVII

Reflecting Power of Rb Mirror No. 1

for λ = 539.6 $\mu\mu$

Plane of Polarization Parallel to Plane of Incidence				Plane of Polarization Perpendicular to Plane of Incidence			
$\frac{O}{I}$		R		$\frac{O}{I}$		R	
Angle of Incidence	λ 539.6	Angle of Incidence	λ 539.6	Angle of Incidence	λ 539.6	Angle of Incidence	λ 539.6
12°	0.806	7°53'	0.814	12°	0.805	7°53'	0.815
20°	0.828	13° 2'	0.837	20°	0.802	13° 2'	0.812
25°	0.837	16°10'	0.847	25°	0.813	16°10'	0.824
30°	0.838	19°14'	0.849	30°	0.808	19°14'	0.818
40°	0.843	25° 3'	0.854	40°	0.801	25° 3'	0.812
50°	0.850	30°18'	0.862	50°	0.789	30°18'	0.801
60°	0.863	34°47'	0.877	60°	0.795	34°47'	0.808
65°	0.861	36°39'	0.877	65°	0.785	36°39'	0.798

To the author's knowledge, no other investigation on Rb has ever been carried out, so that comparison is impossible. Great faith is, however, placed in the curves for Rb, since the results obtained for green light for two different mirrors check very well with each other. (See Tables XVI and XVII)

The reflecting powers given are with reference to glass as the adjacent medium. Were the metals in contact with a vacuum, the results would have been slightly higher. The magnitude of this increase might be obtained as follows. Taking Duncan's results for K for λ = 589.3 $\mu\mu$ i.e., n = 0.068 and κ = 22.1, we obtain a value of 0.92 for the reflecting power by substituting in the formula for

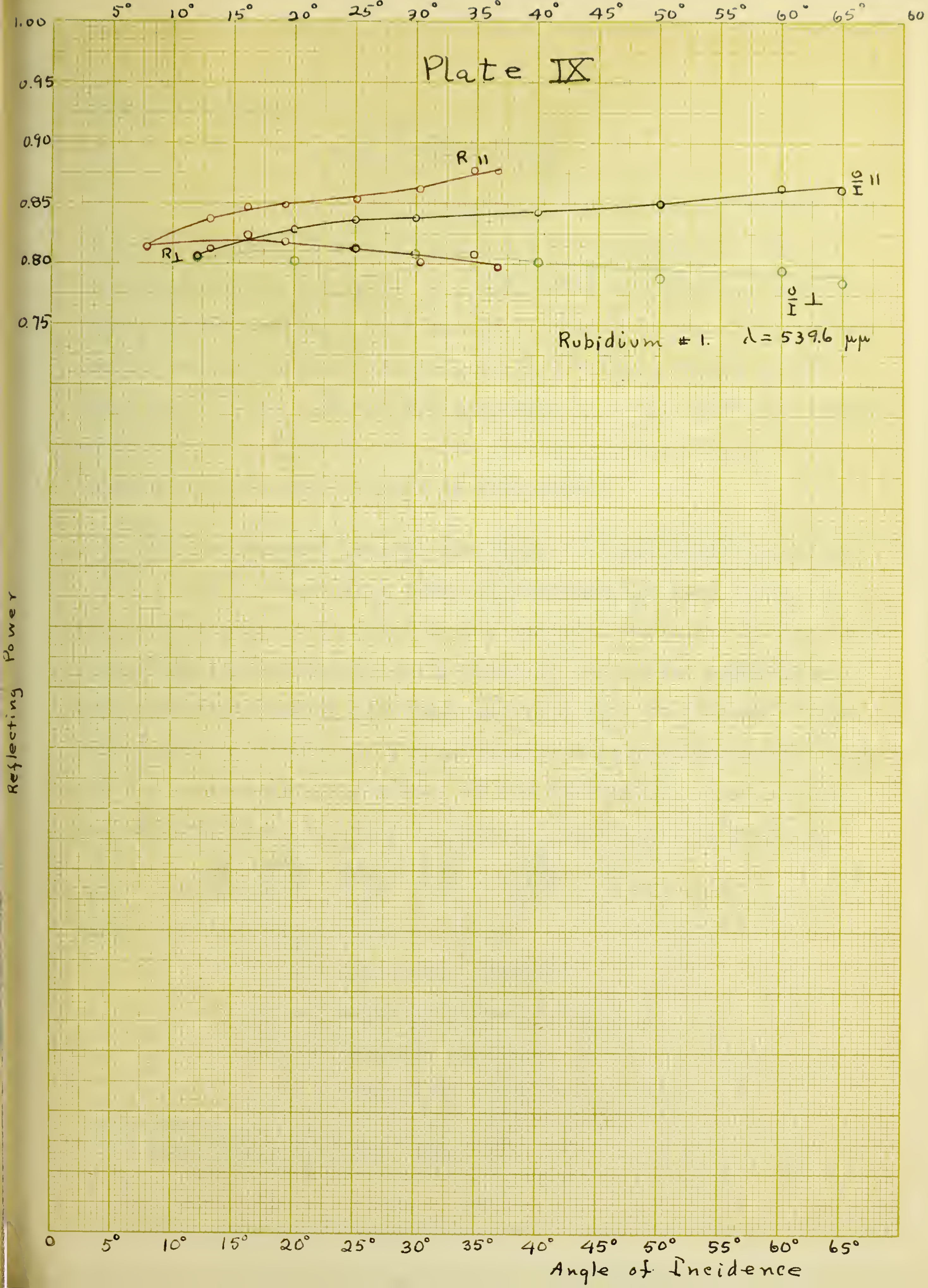


Plate IX
$R_{\parallel}$
$R_{\perp}$
$\frac{O}{I}\parallel$
$\frac{O}{I}\perp$
Rubidium # 1. $\lambda = 539.6\ \mu\mu$
Reflecting Power
Angle of Incidence
1.00
0.95
0.90
0.85
0.80
0.75
0
5°
10°
15°
20°
25°
30°
35°
40°
45°
50°
55°
60°
65°

normal incidence,

$$R = \frac{n^2(1+\kappa^2) + 1 - 2n}{n^2(1+\kappa^2) + 1 + 2n}$$

It has been shown by Ingersoll[15] that the reflecting power of metals in contact with a vacuum can be obtained from the reflecting power of the metal in contact with a medium of refractive index, m, by dividing n by m and substituting in the above formula for R. In our case, m = 1.5155, so that R would become in the above case 0.914. The reflecting powers as is given in the tables would thus be a fraction of a per cent higher were the metal in contact with a vacuum instead of with glass.

V Relation Between Optical and Electrical Properties of Metals

Let us consider a plane electromagnetic wave traveling in an x direction, and incident upon a metallic surface. If the latter medium is considered partly metallic and partly insulating, then both ohmic and displacement currents will be induced in the metal, and the electrical energy will soon be absorbed in the metal.

The equation of motion of the wave in the mixed medium, as derived from Maxwell's electro-magnetic equations, is given by,

$$\frac{k\mu}{c^2}\frac{\partial^2 E_z}{\partial t^2} + \frac{4\pi\sigma\mu}{c^2}\frac{\partial E_z}{\partial t} = \frac{\partial^2 E_z}{\partial x^2} \quad \ldots\ldots\ldots \quad (10)$$

where E_z = electric force

k = dielectric constant

μ = magnetic permeability

c = velocity of light

σ = electrical conductivity (e.s.u.)

15 Phys. Rev., 29, 392, 1903

The solution of (10) must represent a damped oscillatory wave and can therefore be represented by

$$E_z = Ae^{jw(t-px)} \tag{11}$$

where p is complex, and w = frequency per 2π seconds. A complex value of p indicates a damped oscillation. Now the current in the mixed medium is given by

$$i_z = \frac{\sigma E_z}{c} + \frac{k}{4\pi c}\frac{\partial E_z}{\partial t} \tag{12}$$

where the first term on the right hand side of the equation represents the ohmic current, and the second term represents the displacement current. Differentiating (11) with respect to t, solving for E_z and substituting in (12), we have

$$i_z = \left(k - \frac{4\pi j\sigma}{w}\right)\frac{1}{4\pi c}\frac{\partial E_z}{\partial t} \tag{13}$$

If $k - \frac{4\pi j\sigma}{w}$ be replaced by k', then (13) becomes the ordinary expression for a displacement current in a dielectric, where k' is the new dielectric constant. Consequently (10) can be written in the form,

$$\frac{k'\mu}{c^2}\frac{\partial^2 E_z}{\partial t^2} = \frac{\partial^2 E_z}{\partial x^2} \tag{14}$$

which is nothing more than the equation of an electro-magnetic wave traversing a dielectric, whose velocity v is given by

$$v = \frac{c}{\sqrt{k'\mu}} \tag{15}$$

The index of refraction of the metal is thus given by

$$n = \frac{c}{v} = \sqrt{k'\mu} \tag{16}$$

The solution of (10) thus becomes accomplished through the solution of (14). In order to determine the value of p, equation (11) is

differentiated and the results substituted in (14), which then yields the identity

$$p^2 \equiv \frac{k'\mu}{c^2} \equiv \frac{k\mu}{c^2} - \frac{4\pi j\mu\sigma}{wc^2} \qquad (17)$$

Now p is complex, and equation (17) shows it to be the inverse of a velocity. Unfortunately English and German[16] texts differ as to the value assigned to p, so that much confusion has resulted. Both systems are given below.

English		German	
Let $p = \frac{1}{v} - \frac{k\kappa_e}{v}$	(18)	Let $p = \frac{1}{v} - \frac{j\kappa_g}{c}$	(18')

So that $\kappa_g = n\kappa_e$ where n = index of refraction. Equating real and imaginary parts of (17) and (18) or (18')

$n^2(1-\kappa_e^2) = k\mu$	(19)	$n^2 - \kappa_g^2 = k\mu$	(19')
and $n^2\kappa_e = \sigma\mu T$	(20)	$n\kappa_g = \sigma\mu T$	(20')

where T = period of incident waves, and κ is the coefficient of extinction. Since σ is in e.s.u., it must be multiplied by c^2 if it is to be expressed in e.m.u.

The reflecting power of a metal is given by

$$R = \frac{n^2 + \kappa^2 - 2n + 1}{n^2 + \kappa^2 + 2n + 1} \qquad (21)$$

where the German notation is used. The dielectric constant k, and magnetic permeability μ will be taken as unity, since we are dealing with light waves incident on a metal in a vacuum. Hence

$$R = 1 - \frac{4n}{n^2 + \kappa^2 + 2n + 1} \qquad (22)$$

In order to express R as a function of the period of the incident waves, n and κ must be eliminated by the aid of equations (19') and (20').

16 Drude's Physik des Aethers

Let $k = \mu = 1$, then

$$n^2 = \frac{1}{2} + \frac{1}{2}\sqrt{1 + 4\sigma^2_{e.m.}c^4T^2} \tag{23}$$

$$\kappa^2 = -\frac{1}{2} + \frac{1}{2}\sqrt{1 + 4\sigma^2_{e.m.}c^4T^2} \tag{24}$$

Now in the case of metals, the term $\sigma^2_{e.m.}c^4T^2$ is very large compared to unity so that the above equations become

$$n^2 = \sigma_{e.m.}c^2T \tag{25}$$

$$\kappa^2 = \sigma_{e.m.}c^2T \tag{26}$$

Equation (22) thus becomes

$$R = 1 - \frac{2}{\sqrt{\sigma_{e.m.}c\lambda}} \tag{27}$$

Hence as the wavelength λ increases, the second term diminishes, and R increases, becoming unity for $\lambda = \infty$.

The variation of R for the alkali metals as a function of λ is shown on Plate X. There is a distinct rise of the reflecting power with increasing wave length, thus confirming theory. The points on the curves represent the mean of the reflecting powers for light polarized parallel and perpendicular to the plane of incidence, and for an angle of incidence of 12°. The mean therefore represents pretty closely the reflecting power at normal incidence to which the equation (27) applies.

In the case of Rb, the black curve represents the mean position of the points. The dotted red line passes right through the points and shows a slightly abnormally high reflecting power between $\lambda = 450\,\mu\mu$ to $575\,\mu\mu$. This coincides approximately with the region of the selective[17] effect in Rb. Nevertheless the evidence is inconclusive since the reflecting power for light polarized perpendicular to the plane of incidence is, with a few exceptions, always

17 Hughes' "Photo-Electricity", p.83

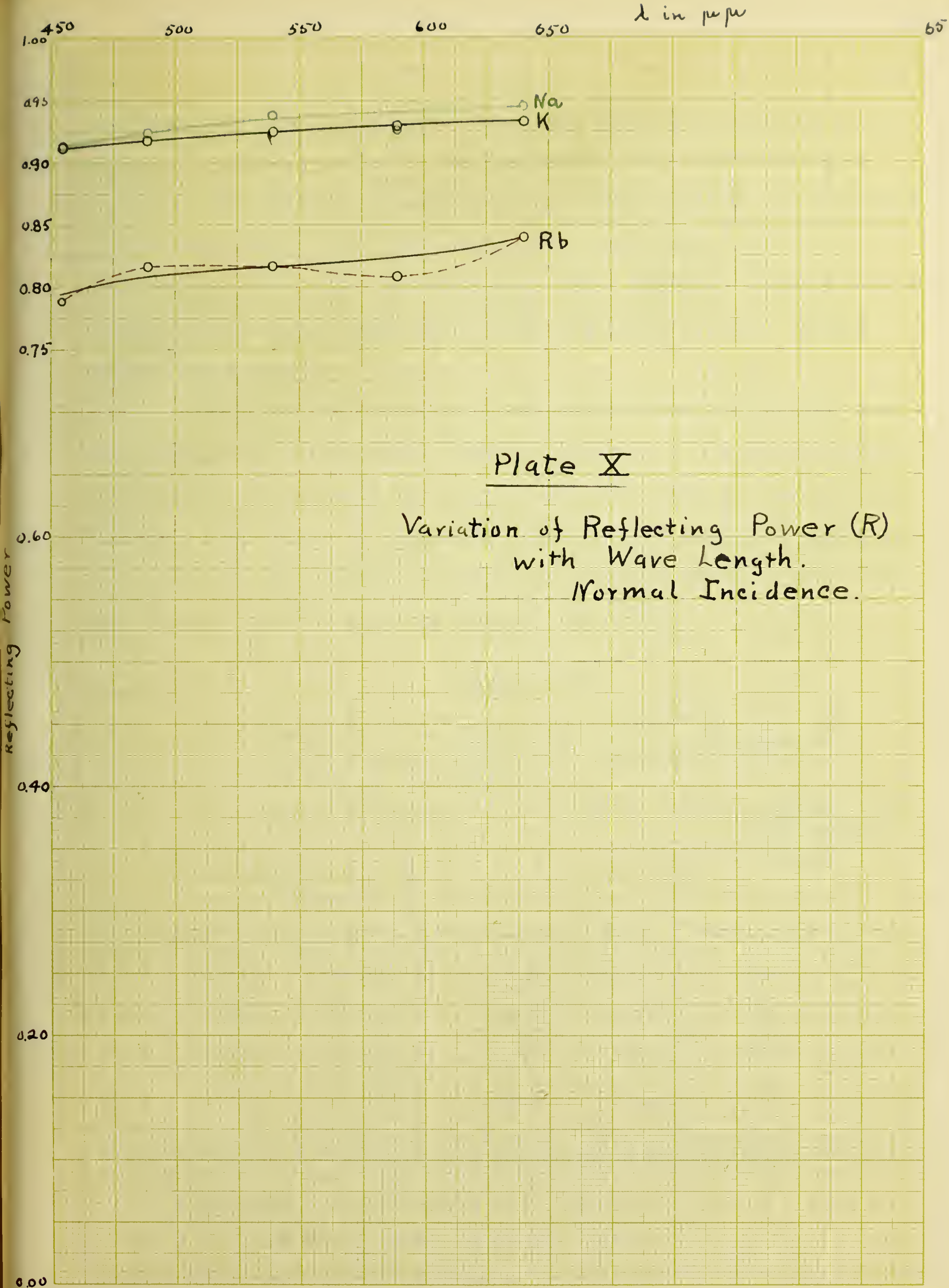


Plate X

Variation of Reflecting Power (R) with Wave Length.
Normal Incidence.

less than the reflecting power for light polarized parallel to the plane of incidence, while if the selective effect were due to a change in the optical properties of the alkali metals, we should expect an abnormally high reflecting power for light polarized perpendicular to the plane of incidence. This point is brought out more clearly by Plate XI, where the reflecting power for $\parallel$ is always greater than for $\perp$.

In Table XVIII are given the experimental values for the reflecting powers for nearly normal incidence, i.e., the averages of the reflecting powers for light polarized parallel and perpendicular to the plane of incidence, the angle of incidence being 12°. The values of the reflecting powers as given by equation (27) have also been calculated and enclosed in this table.

TABLE XVIII

$$\left.\begin{array}{l}\sigma_{e.m.} \text{ for Na} = \dfrac{1}{5072} \text{ e.m.u. } (21°.7) \\ \sigma_{e.m.} \text{ for K} = \dfrac{1}{7010} \text{ e.m.u. } (20°.7)\end{array}\right\} \text{Hornbeck}^{18}$$

$$\sigma_{e.m.} \text{ for Rb} = 71 \times 10^{-6} \text{ e.m.u. } (19°.3) \quad \text{Guntz and Broniewski}^{19}$$

Wave Length $\mu\mu$	Na		K		Rb	
	Experimental	Theor.	Experimental	Theor.	Experimental	Theor.
640.9	0.945	0.897	0.933	0.879	0.840	0.829
589.3	0.926	0.893	0.930	0.874	0.808	0.822
539.6	0.938	0.888	0.925	0.868	0.817	0.814
488.8	0.924	0.882	0.918	0.861	0.816	0.804
454.6	0.914	0.878	0.912	0.857	0.789	0.797

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18 Phys. Rev., 2, Series II, 217, 1913

19 C.R., 147, 1474, 1908; 148, 204, 1909

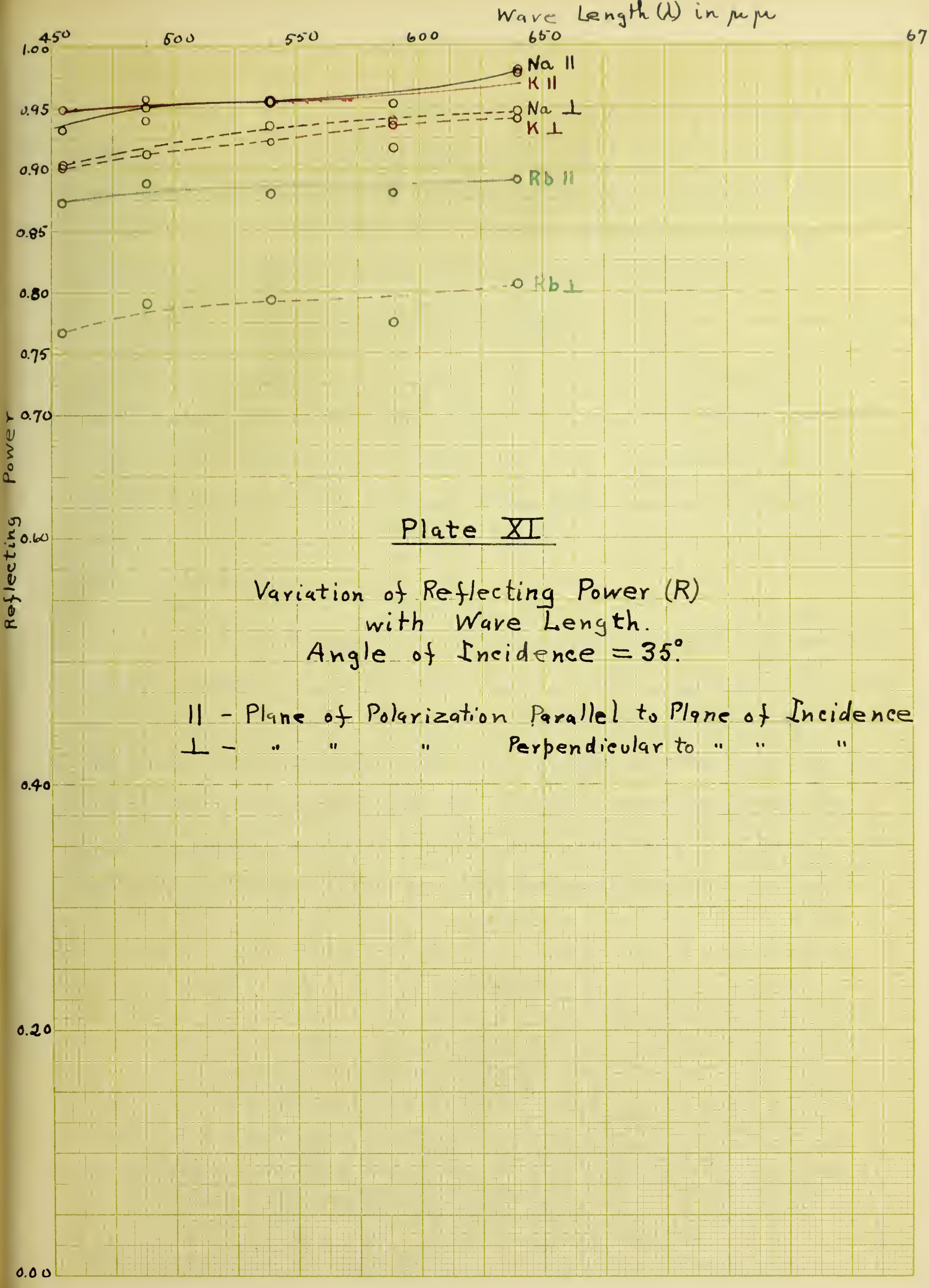

Plate XI

Variation of Reflecting Power (R)
with Wave Length.
Angle of Incidence = 35°

∥ - Plane of Polarization Parallel to Plane of Incidence
⊥ - " " " Perpendicular to " " "

In general the theoretical values are lower than the experimental, though the agreement in the case of Rb is very close. The reflecting power of Rb is thus confirmed by Maxwell's equation of reflection. The discrepancy between theory and experiment becomes more marked if we put equation (27) in the form

$$\frac{(1 - R)}{2} \sqrt{\sigma_{em.} c} = \frac{1}{\sqrt{\lambda}} \tag{28}$$

The value of the expression on the left hand side of the equation appears to be only a function of the wave length, and hence ought to be independent of the metal used. Calculations for λ = 640.9 $\mu\mu$ made with Na, K and Rb show, however, that the values of the left member of equation (28) are respectively 66.9, 69.3, and 117, while $\frac{1}{\sqrt{\lambda}}$ = 124.4

This discrepancy between theory and experiment shows that Maxwell's equations do not hold for the visible spectrum. In view of the modern electron theory, this is not at all surprising, for Maxwell's theory does not take into account the effect of the electrons within the metals upon the incident electro-magnetic waves. That the agreement holds very good for large wave lengths was shown by Hagen and Rubens[20] for wave lengths ranging from 8 to 15 μ.

20 Ann. d. Phys., 11, 873, 1903

SUMMARY

1 The reflecting powers of Na, K and Rb were determined for various angles of incidence, using white unpolarized light, and also monochromatic light polarized parallel and perpendicular to the plane of incidence.

2 A Rb-argon photo-electric cell was used as a photometer. It was calibrated in terms of known light intensities by means of crossed Nicols. The photo-electric current was found not to be strictly proportional to the light intensity.

3 The alkali metals were used in the form of mirrors, which were made by distilling or pouring the metal on a glass plate forming a part of an evacuated cell.

4 Due to reflection at the front and internal faces of the glass plate, the optical properties of the glass plate were determined in order to calculate the reflecting power of the metal itself. Fresnel's reflection equations for glass were verified.

5 The reflecting powers of Na, K and Rb were found to decrease in the order named, i.e., as their atomic weights increased. The values for monochromatic light were found to be somewhat higher than those for white light. In the case of Na and K, the results were in fair agreement with those of R. W. and R. C. Duncan. The results for Rb were found to be confirmed by Maxwell's equation for metallic reflection.

6 In the case of monochromatic polarized light, the reflecting power increased with increased angle of incidence, for light polarized parallel to the plane of incidence, but decreased somewhat for light polarized perpendicular to the plane of incidence for the range of angles used.

7 The reflecting powers increased with increase of wave length in accordance with Maxwell's theory.

8 The selective photo-electric effect does not seem to be due to any marked change in the reflecting powers of the alkali metals for light polarized perpendicular to the plane of incidence.

In conclusion, I wish to take this opportunity of expressing my thanks to Professor A. P. Carman for having so kindly placed the necessary facilities for research at my disposal, and to acknowledge my indebtedness to Professor Jakob Kunz for having suggested this problem, and for his many valuable and kind suggestions throughout this investigation.

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V I T A

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"A Determination of e/m and v by the Measurement of a Helix of Wehnelt Cathode Rays." Physical Review, 2, 307, 1913

"The Reflecting Power of Alkali Metals in Contact with Glass, as Determined by the Photo-Electric Cell." (Abstract) Physical Review, 7, 403, 1916.